How Formative Assessments Influence Academic Performance of Undergraduate Engineering Students: A Systematized Literature Review

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Abstract

Assessment is commonplace among educators, with routine homework assignments, quizzes, and exams comprising a significant portion of a typical college student's weekly activities. While these activities contribute to skills practice and provide the instructors some measure of student mastery, they may actually place more emphasis on an end goal of rapid but superficial development rather than potentially more time consuming but deeper learning. Often overlooked by educators is the value of integrating formative assessments with these measures to gauge student learning progress and identify hindrances to learning. This systematized literature review examines current studies involving both instructor evaluated as well as student self-evaluated assessments used as a strategy to track the progress of learning and foster deep conceptual understanding. Four databases representing peer reviewed educational and engineering articles were searched yielding 94 unique studies, with 17 meeting all review criteria. Results showed generally positive student reception toward and improved learning outcomes from studies of formative assessment, but effectiveness was mixed in some applications, indicating attention must be given to conflicting goals between students and instructors. Formative assessment may provide valuable, low consequence feedback regarding actual levels of understanding and learning progress, however the effort can be time intensive for all. The quality of outcomes may be linked to the investment of each party, however the potential gains appear worth the investment. A balance of assessment style and delivery must be achieved, and may need to be tailored to each particular learning environment.

Keywords: formative, assessment, undergraduate, student, self-assessment, engineering, education

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While assessments in academic settings take many forms, typically they fall into two broad categories: formative or summative (Harlen & James, 1997). Summative assessments are generally most familiar to both students and instructors, consisting of discrete evaluable exercises designed to gauge a student's performance relative to a norm or peer levels. These would include instruments such as term papers, final exams, and class projects. The end goal is to classify the state of student ability or understanding without particular emphasis on further improvement. Formative assessments are encountered less frequently or at least presented less formally. These would include ongoing evaluations of developing skills, with the intent of actively modifying behaviors to elicit further improvement. The end goal is not to judge current knowledge or rate of development, but to assess hurdles to understanding allowing unfettered progress toward mastery (Black, 1988). Examples include draft assignments to explore thought processes, journaling to promote reflection, and visualization of concepts to validate fundamental connections. It is this latter type, formative assessment, that will be the focus of this review.

Purpose and Motivation

A key goal of any educator is to matriculate students with a sound grasp of concepts which may be carried forward and applied in combination with any number of others to solve meaningful problems. Such applied use of knowledge generally requires more than a superficial understanding of topics. Unfortunately, superficial linkages are often the result of student learning (Rhem, 1995). Although fundamental concepts are typically presented as a matter of course when teaching new material to students, without adequate references or context these are often left isolated, requiring explicit effort for the student to recall and not easily transferred to unique situations (Bransford, Brown, & Cocking, 1999). A deeper learning, allowing the core concepts to become part of the students' consciousness rather than isolated parcels of information, is necessary. A vital aspect to developing this deep learning can be the proper use of formative assessments (Rushton, 2005).

Formative assessments may involve, but are not limited to, direct instructor evaluation of student performance, questionnaires, or visual observations. They may also involve student self-assessment activities, such as journaling, keeping a personal diary, reflective writing exercises, and independent skill development (via automated feedback). Self-assessment activities may be coupled with instructor evaluation, or may be left solely for the benefit of the student. Other types of formative assessment involve the use of student peers in reviews of each other's work, collaborative community problems (e.g. online peer discussion and support forums), as well as peer teaching activities.

For the purpose of this review, consideration is given only to instructor and self-assessment activities as they influence student performance in academic settings. Peer assessment practices, while potentially valuable, are not specifically evaluated here. Of primary interest is how clarity in understanding of comprehension from the student perspective may be affected by such formative assessments. Three themes related to the effects of formative assessment on performance emerged during this review; they are student encouragement, enlightenment, and empowerment. These are supported by a few focus areas that were found to recur in the literature, and will be discussed later.

Scope and Research Question

The scope of this systematized literature review was defined using the EPICOT framework, as illustrated in Table 1 (Brown et al., 2006). The studies examined include evaluations of student response to and benefit from formative assessments as compared to previous or concurrent traditional or alternative treatments. This review addresses two primary research questions: How do undergraduate engineering students respond to formative assessment activities within an academic course setting and in what ways do students benefit from these assessments?

Using methods described by (Borrego, Foster, & Froyd, 2014), the following procedure was adopted to select databases, develop search strings, and select articles for inclusion into this review.

Table 1

EPICOT Framework for Research Question Formulation

Component	Application
Evidence (of need)	Varied or inconsistent application of assessment types in academic courses
Population	Undergraduate engineering students
Intervention	Application of formative assessment activities (self or instructor assessed)
Comparison	Alternative or no formative assessment
Outcomes	Studies describing effects on student academic engagement and performance
Timeline	September 30, 2016

Methods

Database Selection

For this review, I considered online databases representing either education or engineering and technology research. ERIC and Education Source (hosted through EBSCO Information Services) provided comprehensive access to education research journals while ProQuest Technology Collection provided journals covering all engineering and technology fields. Scopus provided a large base of research literature across many scientific, technological, and humanity fields that may have been missed in the other more specific databases. I desired to access an encompassing selection of research related to the field of engineering but focused on assessment activities as related to student academics. During exploratory searches, more specific databases such as Compendex and PsychInfo provided significant returns, but yielded little satisfying the above criteria and unique from the returns of the aforementioned databases. To limit the scope and reduce diminishing returns on effort, I chose to select the initial four databases to obtain the base of peer reviewed journal articles used in synthesizing this systematized review.

Search Strings

I selected initial keyword phrases for the search queries based on the text of my research questions. Through iterative refinement, I attempted to remove definitional ambiguities while maintaining maximum inclusivity. The defined article return-target of $n \approx 100$ drove the search string specificity. Key phrases of interest were "engineering education", "formative assessment", and "undergraduate student". Further refinement included adding "self" and "evaluation" as alternates for formative and assessment respectively. Alternatives for undergraduate included "university", "college", and "post-secondary". Table 2 illustrates the various strings utilized between databases. Boolean operators and wildcards provided manual stemming (auto-stemming did not result in the desired refinement of results). Proximity operators (e.g. N, NEAR, W, PRE) provided flexibility in phrasing and word placement while restricting inclusion of disconnected uses. All proximity parameters represented equal maximum spacing.

As ERIC and Education Source utilized the same hosting service, their search strings are identical. ProQuest uses the same base string while substituting proximity operators. Additionally, the ALL operator for ProQuest restricts database searches to areas outside of the full document text (e.g. abstract, title, subject). The default for ERIC and Education Source utilizes similar fields when full text is not specified. For Scopus, I used the KEY operator to limit the returns to a manageable number. SCOPUS defaults to an ALL operator (i.e. all but full text), but the structure of the SCOPUS database fields returns 40 to 50 times the results of an equivalent search operation in the remaining databases. Upon examination, these SCOPUS results appeared inadequately focused. The KEY operator however relies on an author supplied and journal assigned keyword vocabulary, resulting in search returns with comparable scope to the other databases. Additionally, SCOPUS contains a restriction in mixing proximity operators, wildcards, and parenthetical groupings. As a result, the “post-secondary” key words had to be specifically defined.

Table 2

Search String Variations by Database

Database	Initial Number Found	String
ERIC	43	((engineering N4 education) AND ((self OR formative) N4 (assessment OR evaluat*)) AND (college OR universit* OR undergrad* OR (post W1 secondary)) N4 student*)
Education Source	37	((engineering N4 education) AND ((self OR formative) N4 (assessment OR evaluat*)) AND (college OR universit* OR undergrad* OR (post W1 secondary)) N4 student*)
ProQuest	28	ALL((engineering NEAR/4 education) AND ((self OR formative) NEAR/4 (assessment or evaluat*)) AND ((college OR universit* OR undergrad* OR (post PRE/1 secondary)) NEAR/4 student*))
SCOPUS	12	KEY ((engineering W/4 education) AND ((self OR formative) W/4 (assessment OR evaluat*)) AND (college OR univesit* OR undergrad* OR "post-secondary" OR "post secondary") W/4 student*)

Inclusion and Exclusion Criteria

All database search results included only peer reviewed journal articles (including in-press). As indicated in Table 1, the initial search results (as executed on September 30, 2016) yielded 120 articles. Further selection was done as shown in Figure 1. Merging and removal of duplicates yielded 94 articles. Analysis of abstracts further limited the final selection. This review required studies to focus on undergraduate students (rather than other levels or staff), include some mention of formative or self-assessment (or similar terminology), not limit itself to peer-assessments, involve in school rather than out of school settings, address student assessment rather than that of a program or curricular implementation, focus on engineering students or involve curricula relevant to engineering students (e.g. programming, mathematics), and relate to academic issues rather than professional development (e.g. team building). Abstract analysis reduced the article selection to 32.

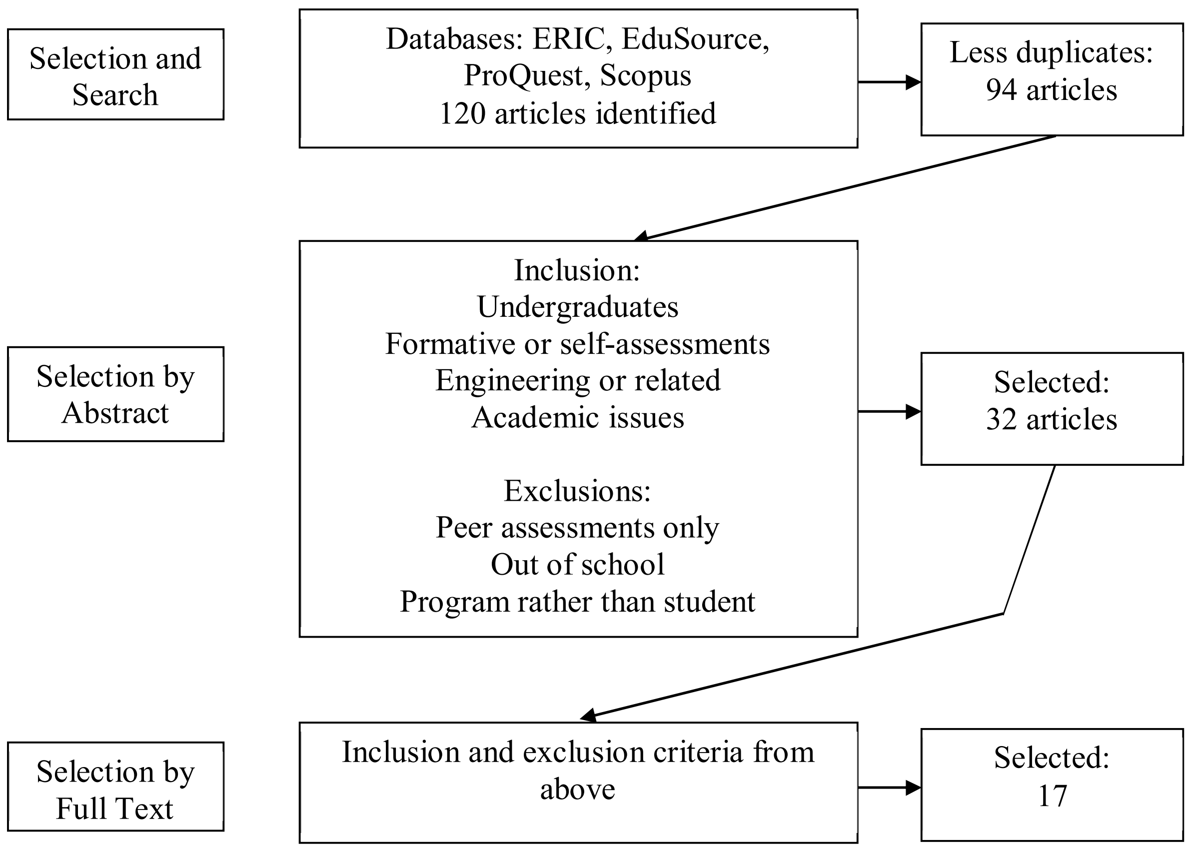

Figure 1. Selection process database articles

Full text review against these criteria further limited final selections. One consisted of a commentary and four included out of class (i.e. non-classroom), non-academic, or non-engineering students. One included primarily peer assessments while another focused on assessment of a field rather than student assessment. Finally, eight involved assessment of a course, system, or program rather than student learning. The final article collection consists of 17 peer-reviewed research articles which meet the described selection criteria and are described in Table A1.

Results

I will now highlight a few focus areas that emerged during this review. These topics played key and recurring roles in how formative assessments appeared to affect undergraduate engineering students. This list is by no means exhaustive, but serves as a foundation for some overarching themes to be discussed.

Source of Assessment

Students exhibit generally positive responses toward formative assessment activities. The value placed on these assessments various according to their source, which may be self or peer based. Although peer assessment was not a focus in this study, the available articles described both self and peer assessments as the most effective in improving performance, although students prefer self to peer. Peer assessments were also similar in effectiveness to those of instructors in regard to improving student understanding. Nonetheless, students placed increased weight in instructor assessments (De Sande & Godino-Llorente, 2014). The proximity of an assessor to the power of grade assignment appears to correlate positively with the value students associate with the assessment activity. The quality of such input may not correlate in a similar fashion however (Rodgers et al., 2015).

Feedback

Students engaging in formative assessment activities desire and benefit from feedback. Despite their best efforts, instructors may not always provide the feedback desired, in quantity or quality. Both require commitments of time that may exceed that available to them. When assessments are automated through technology, meaningful feedback requires meticulous attention to the responses given to user input. This may be particularly time consuming (Dexter, 2010).

When feedback is provided, prompt responses are most valuable. Real time feedback to in-class activities, such as problem solving, provides students with a sense of individualized attention (Chung, Shel, & Kaiser, 2006). Prompt feedback provides students the opportunity to improve time management and recognize the expectations of and commitments required to succeed in learning endeavors (Wellington & Collier, 2002).

Students value feedback specific to their situation. They invest little time processing generalized or vague responses (Rodgers et al., 2015). Effective feedback must provide some form of guidance for the student. Merely supplying the correct answers to students in response to formative exercises is insufficient, even in the simplest of cases (Walker & Palmer, 2011). Something more directive which provides guidance to the student is required. Walker and Palmer (2011) even suggest consideration of an exemplar feedback class in addition to the outcome, corrective, and process classes described by Peterson and Irving (2008). Such feedback would include examples of prior student work to guide current student efforts.

Anonymity

Students also appreciate the ability to interact with an instructor in an environment supporting questions and guidance without perceived judgement and grade penalties. Automated systems which provide digital screening of the student are particularly effective (Chung et al., 2006). Active learning tasks, such as interactive problem solving during lectures, benefit from instructors knowing in real time how students are performing on problems related to a given topic. Students however, may only perform at their true level when they feel free of judgement and consequence. Shielding their identity allows uninhibited participation, promoting increased engagement. Instructors may still gauge the overall grasp of difficult concepts while identifying trouble areas and steering the lecture in the most effective direction toward progress (Roselli & Brophy, 2006).

Engagement

Formative assessments combined with innovations such as mobile or handheld technologies integrated into problem solving can stimulate waning attentiveness and engagement in lecture students. Real time feedback from active learning activities can improve attentiveness in students as they quickly realize if they are not able to successfully complete presented exercises. Timely realization of misunderstandings may result in sharper focus by students when an instructor proceeds to clarify misconceptions. When students arrive at conflicting results, instructors may initiate class-wide discussions requiring students to argue their results with peers, providing both engagement opportunities and a deeper analysis of the problem solving processes (Roselli & Brophy, 2006).

Reflection on one's own work exposes faulty assumptions and gaps in foundational understanding. Unconsidered limitations or options for forward progress may be exposed given the opportunity to review completed or ongoing projects. Design review supporting deeper consideration of decision processes and potential alternatives may have significant positive effects on product quality (Pierrakos, Barrella, & Stoup, 2015). A common characteristic of strong or high-performing students is a self-motivated desire to improve understanding, a trait supported by regular self-reflection (Gynnild, Holstad, & Myrhaug, 2008).

Additionally, routine application of formative assessments provides students with an incentive to invest additional time into subjects, as well as improve management of the time applied to learning goals (Wellington & Collier, 2002). Where summative assessments provide little post-incentive for additional review, formative assessments focus on improvement and encourage students to review and clarify learning materials (e.g. subject notes) in a way that they may never attempt otherwise (Sorensen, 2013). This increased time investment may lead to overall performance gains for students (Tlhoaele, Hofman, Winnips, & Beetsma, 2014).

Awareness of Understanding

Summative assessments may be transformed into formative opportunities through the addition such activities as answer explanations or requesting student responses to grading feedback. Explanations engage students to justify reasoning and avoid logical leaps when formulating their initial responses (Hanson & Williams, 2008). Requiring responses to grading feedback encourages further consideration of thought processes and recognition of conceptual misunderstandings (Kagesten & Engelbrecht, 2006), again encouraging students to review materials which may typically be otherwise neglected.

Feedback such as these also present the instructor with an opportunity to assess student confidence as well as correctness. At times, students may exhibit confidence levels at odds with their actual comprehension of fundamental concepts. If these are out of alignment, students may progress down fruitless paths of continued misunderstanding. Yuen-Reed and Reed (2015) suggest that nearly one third of students may lack confidence in their correct understanding of a topic while nearly one half may exhibit abundant confidence in a flawed understanding. This represents a dangerous bias in regard to how engineers may sway one another away from sound decisions.

Improvement in Performance

Formative feedback, especially if focused toward enhancing problem solving skills, may not always result in overall improved performance. While some instances showed positive improvements when integrated with continued self-practice on automated systems (De Sande, 2011), others have shown negative overall performance gains despite improved intermediate performance, possibly attributable to overdevelopment of false confidence (Hannah, James, & Williams, 2014). Nonetheless, students tend to weight assessment activities and corresponding feedback according to its likelihood to affect their course grades (Rodgers et al., 2015). Much of any noticeable improvements appear to result from improved time investment, management of learning goals, and student self-refection (Gynnild et al., 2008; Tlhoaele et al., 2014; Wellington & Collier, 2002). Students must strive to improve their own understanding of their knowledge, particularly their knowledge limits, to perceive positive improvements in performance. Students with unrealistic views of their own performance may suffer from decreased course satisfaction (Walker & Palmer, 2011) and risk further academic disengagement.

Discussion

The previously described focus areas may be grouped into an overarching set of themes which describe the effect formative assessments may have on undergraduate engineering students. As the topic of this review is how formative assessments influence student performance, I have divided the themes as follows: student encouragement, enlightenment, and empowerment.

Encouragement

Encouragement implies promoting students to more fully engage with the educational process, be active learners willing to put forth their ideas, and accept feedback and even criticism intended to bolster their development. Contributing factors include engagement, feedback, and potential anonymity. Formative assessments provide students with a number of opportunities to engage in low-risk but potentially beneficial academic development activities. Interactive problem solving, classroom discussion, and defense of solutions provides invaluable practice opportunities in addition to deeper consideration as to why a particular solution may or may not be justified. Interactions with peers during discussions and dynamic lecturing practices by instructors able to assess the progress of students' learning aid in reinforcing confidence and exploring the limits of one's abilities. Particularly when coupled with the potential anonymity offered by technological integration, students may be emboldened to participate and push the limits of their skill well beyond that experienced in traditional settings.

Timely and effective feedback, targeted toward individual students and providing enough guidance to help maintain their momentum through difficult topics is key. Students must have something of substance to consider, eliciting a reflective response when digesting any analysis of their efforts. Answers alone are not enough, but too many specifics may also spoil the delicate balance required to maintain engagement.

Enlightenment

Enlightenment indicates students becoming more self-aware of their own learning objectives in addition to those of their instructors, acknowledging their limitations and adjusting behaviors to help overcome them, and working to integrate rather than merely assimilate knowledge. With a limited frame of reference, students may not be the best gauge of their own progress. As a result, both formative and summative assessments play important roles in keeping students apprised of their own awareness of understanding. Instructors who successfully encourage students to consider their work deeply may bring about more thought and considered solutions to engineering problems. One should not overlook the benefits of continued learning opportunities either. Typical summative work encourages students to put their best effort forward, often resulting in a final evaluation and the end of a topic. Formative assessment may further the learning cycle to a place of reflection and personal consideration of students' thought processes. Much may be gained from further consideration of completed assignments.

In addition to reviewing the process of solving problems, students may gain perspective on the extent or limits of their own knowledge. It may not be enough to know a subject as well as one can. It may be more valuable to clearly recognize what one does not know, and when to take compensatory actions. Confidence in one's work may be important to progress skills, but mislaid confidence may be far more detrimental as it begins to negatively affect the work of others as well.

Empowerment

Empowerment provides a means for students to take control of their academic development; to become a part of the process rather than a mere recipient for it. Students have many choices to make in the academic process. How to apply their limited time, estimation of required commitments for a particular course, and what steps to take to improve are just a few. The ultimate goal for students is to maximize their learning as it relates to a given subject. Students typically gauge this by their performance level in a course. Ideally, a student's perceived performance and demonstrated performance will converge, providing an accurate guide toward their understanding. If these performances do not align however, the result will be a student who experiences frustration and an increasing dissatisfaction with their courses.

Assessments are administered to gauge progress and to help students focus on their progress. Feedback from these assessments are key in communicating guidance to students so they may effectively allocate their available resources in attempts to improve performance. As students must make choices, feedback from varied sources maybe evaluated differently. Since students may equate grade performance with learning success, feedback from grade providers may weigh more heavily. This may not always be the best source of feedback for any given situation, as quality can and will vary. An important consideration is to limit conflicting sources of feedback to prevent students from making ill-conceived choices during self-analysis. This may help them maximize their return on investment of limited resources.

Limitations

Literature reviews are subject to various forms of bias. Of the types described by Rothstein, Sutton, and Borenstein (2005), database bias and publication bias could apply here. A limited number of databases were included in the review process and additional sources certainly could have introduced novel results. As online databases provided the sole source of articles, they were obviously limited to published results. Negative results that failed to publish were not considered. Additionally, reviewer bias (Ernst & Resch, 1994) is also possible. Care was taken to ensure objective analysis of identified article against predetermined selection criteria, but inadvertent biases may still be introduced.

The search strings used for the databases were relatively specific. Relaxation of the terms within the strings, or the database specific limitations such as search restrictions, would also widen the field of potential articles. Additionally, use of the KEY operator with the SCOPUS database to control returned results may not have been the most appropriate choice. Perhaps the larger return pool would have produced a more complete article pool. Limitations in time and manpower however, precluded utilization of such relaxations.

Conclusion

Formative assessments can be a valuable tool to not only gauge student progress without introducing the negative connotations of performance evaluation, but to also stimulate motivation in students to become more involved in their own educations. Typical summative assessments may inform an instructor as to what level a class of students has mastered a set of topics at a given time, but it is merely a snapshot. It does not indicate the efficacy of the instruction to that point, and more importantly, does not provide an opportunity to correct any indicated shortcomings. Formative assessments provide a means to guide and improve instruction in a dynamic fashion while also providing students an opportunity to improve their understanding of concepts.

Aside from providing insight to the instructor, enabling students to improve their own learning performance is a key advantage of formative assessments. The mechanism by which students may achieve improvements may be described in three aspects: student encouragement, enlightenment, and empowerment. Encouragement promotes students to become more fully engaged with the educational process, through confidence building and constructive feedback. Enlightenment allows students to become more self-aware of their own learning objectives, helping them realistically identify their level concept mastery and understanding, hopefully preventing disconnects with learning activity satisfaction. Empowerment allows students to take control of their academic development, making intelligent and efficient choices as to how they should invest their limited resources of time and energy in an effort to maximize learning outcomes.

Acknowledgments

Gratitude is given to Amy Van Epps of the Purdue University Libraries for guidance and invaluable information toward successful navigation of the many research databases.

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Appendix A

Table A1

Thematic Breakdown of Included Articles

Article	Key Points	Key Issues	General Theme
(Bjoerkli, 2015)	Mobile technology to allow instructor review of issues prior to discussion and second chance attempts on problems. Mobile entry of multiple choice answers to problems after period problem consideration without answer choices.	Take Control, Engage	Empowerment, Encouragement
(Chung et al., 2006)	Interactive problem solving and discussion with real time instructor feedback increases sense of individual attention while anonymity increases interaction. Interactiveness increases engagement and positive attitudes toward engineering.	Engage	Encouragement
(De Sande, 2011)	Self-assessment and practice increased overall performance.	Take Control	Empowerment
(De Sande & Godino-Llorente, 2014)	Self-assessment and peer assessment was more effective as a formative assessment than instructor assessment. Peer assessment correlated well with instructor assessment in improving understanding but more confidence placed in instructor assessment. Students prefer self-assessment over peer assessment in most cases.	Take Control	Empowerment
(Gynnild et al., 2008)	Reflection over student's own work is important. Self-motivation is a key characteristic of strong students.	Self-Aware	Enlightenment
(Hannah et al., 2014)	In computer aided assessment, quiz improvements through repeated trials decreased final performance, possibly due to false sense of achievement. This did not help weaker students to catch-up with stronger students.	Take Control, Self-Aware	Empowerment, Enlightenment

Article (continued)	Key Points	Key Issues	General Theme
(Hanson & Williams, 2008)	Explaining the process of solving a problem rather than applying "plug and chug" solutions helps students discover what the limits of their understanding may be.	Self-Aware, Engage	Enlightenment, Encouragement
(Kagesten & Engelbrecht, 2006)	Addition of explanations to submitted answers for full credit exposes uncertainty in knowledge, promotes use of references, following logic pattern of thought, and consideration of alternatives. Some students may fear exposing a lack of understanding and risking grade loss.	Self-Aware, Engage	Enlightenment, Encouragement
(Khachikian et al., 2011)	Students are responsive to performance feedback from assessments on time management and expectations. Students tend to overestimate probable grades and ability to commit time to courses.	Take Control, Self-Aware	Empowerment, Enlightenment
(Pierrakos et al., 2015)	Addition of technical design reviews in capstone project yields increases in qualitative reflection on unconsidered issues and overall quality improvements through increased student engagement and motivation.	Engage, Self-Aware	Encouragement, Enlightenment
(Rodgers et al., 2015)	Feedback should be specific to student's work. More weight placed on feedback from sources affecting student’s grades, even if of lower quality.	Take Control	Empowerment
(Roselli & Brophy, 2006)	Anonymous personal response system keeps instructor informed of student understanding. Instantaneous nature promotes participation and engagement of class in discussion of answers. Students support and convince neighbors with their solution. Decreases inhibition, increases attentiveness when personal misunderstanding is realized. Instructor may identify misconceptions and inadequate prerequisites.	Take Control, Self-Aware, Engage	Enlightenment, Encouragement, Empowerment

Article (continued)	Key Points	Key Issues	General Theme
(Sorensen, 2013)	Purpose of testing is to force students to review notes, which otherwise may never happen. To formative quizzes with multiple attempts encourage students to review and revise notes. Final summative quiz with single attempt benefits from prior note revision.	Engage	Encouragement
(Tlhoaele et al., 2014)	Increased self-assessment yields increased time investment and academic performance.	Take Control	Empowerment
(Walker & Palmer, 2011)	Students tend to have a poor idea of their own level of understanding, which may lead to poor levels of personal satisfaction with a course. Feedback must extend beyond merely the correct answers and students must be encouraged to engage with feedback.	Self-Aware, Engage	Encouragement, Enlightenment
(Wellington & Collier, 2002)	Regular formative assessment yields increased attendance and helps students pace and structure learning, increasing motivation and performance. Prompt feedback helps students manage time and gauge necessary commitments.	Self-Aware, Engage, Take Control	Enlightenment, Encouragement, Empowerment
(Yuen-Reed & Reed, 2015)	With confidence based scoring, underperforming is related to "low accuracy in self-assessment". Students assess knowledge reasonably well, but still roughly one third are under confident (may be swayed inappropriately by others) and half are overconfident (may inappropriately sway others).	Self-Aware	Enlightenment