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The perceived importance of active learning techniques in online STEM courses

Montgomery Van Wart [a,*], Mirand McIntyre [b], Jing Zhang [c], Pamela Medina [d,e], Anna Ni [f], Lewis Njualem [g]

[a] Public Administration, California State University San Bernardino, United States
[b] Psychology, California State University San Bernardino, United States
[c] Management, California State University San Bernardino, United States
[d] Public Administration, United States
[e] Associate Professor, California State University San Bernardino, United States
[f] California State University San Bernardino, United States
[g] School of Cyber & Decision Sciences, California State University San Bernardino, United States

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ABSTRACT

It is widely acknowledged that active learning strategies increase engagement and long-term retention, while reducing attrition and frustration of students with less academic preparation and self-efficacy. Promoting active learning methods in STEM has been a long-term project in higher education. This study examines the perceptions of active learning techniques in online STEM education, leveraging a large, diverse sample ($N = 727$) across four STEM fields. The post-pandemic context of the study offers unique insights into how students and faculty perceive the effectiveness of various active learning methods in a rapidly changing educational environment. For eight of the nine methods studied, more than half of students and faculty found each active learning strategy to be helpful for online learning achievement. On average, both students and faculty found active learning methods to be modestly more important in online courses than face-to-face courses. A novel finding that was striking was that by a wide margin, both students and faculty perceived requiring activities more helpful than offering them on an optional basis. This implies that active learning methods become a meaningful portion of the course grade. However, faculty and students disagree on how heavily such activities should contribute to course grades. On average, students believe about half of their grade (52%) should comprise active learning activities, whereas faculty report that 32% of grades in their courses come from formative active learning assessments. The implications of activity-based STEM learning in online courses are discussed.

1. Introduction

Active learning theory holds that deliberately involving students in their learning—in as many ways as possible—is important for an effective education [1]. Chickering and Gamson [2] long ago noted:

> Learning is not a spectator sport. Students do not learn much just by sitting in classes listening to teachers, memorizing pre-packaged assignments, and spitting out answers. They must talk about what they are learning, write about it, relate it to past experiences, apply it to their daily lives. They must make what they learn part of themselves (p. 3).

While there are many definitions of active learning and exactly which activities contribute to it, those definitions agree that it highlights the limitations of teaching primarily by telling and advocates extensive use of supplementary methods that make the learner more than a passive participant in the learning process. Not only do most studies find it aids learning engagement and retention, but it also bolsters self-efficacy [3] and helps enhance self-confidence [4].

Similar to other disciplines, active learning has been found to be very important in various STEM settings from introductory to advanced courses [3,5–10], although researchers have found use of active learning methods has only improved modestly [11,12]. In addition, active learning methods have been found to be consistently more effective in

* Corresponding author.
E-mail addresses: mvanwart@csusb.edu (M. Van Wart), Miranda.mcintyre@csusb.edu (M. McIntyre), Jing.zhang@csusb.edu (J. Zhang), Pamela.medina@csusb.edu (P. Medina), yni@csusb.edu (A. Ni), lewis.njualem@csusb.edu (L. Njualem).

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contexts with STEM students from minoritized groups [13,14] as well as with students who have weaker self-regulation [15]. Since disciplinary differences in teaching are significant [16–19], it is useful to know in the post-COVID era how and to what degree *specific* active learning strategies are perceived to be important for STEM disciplines in *online* contexts, how their perceived effectiveness varies from face-to-face contexts, to what degree active learning in online contexts might affect formative assessment grading, and the extent of agreement among students and faculty on these issues.

Active learning occurs inside and outside the physical or virtual classroom whatever the modality [20, Author]. Active learning in physical or virtual classroom settings can include: [21] auxiliary laboratory sessions in general, [22] laboratory sessions with peer collaboration, [16] polling students in physically present or synchronous classes, [23] synchronous review sessions focusing on student questions rather than lecture, [24] small group discussions as a part of the lecture or in lieu of it, and [25] questions interposed in lectures, among others.

Active learning methods outside the physical or virtual classroom can include purely student-directed activities such as term papers and individual or group projects. However, for this study we focus on those active learning methods outside the classroom format that are instructor-facilitated; we refer to these as instructor-designed, study-and-review activities. Three prominent ones are [26] practice quizzes and practice exams, [27] instructor-generated study guides, and [17] automatically-graded problems/questions accompanying study materials.

One aspect of this post-pandemic study explores student and faculty of perceptions of the efficacy of various active learning methods individually. This is not to suggest that there is a single best method—far from it. A mix of active methods has long been considered a key to good teaching as our introductory quote highlights (see, for example, [26, 28–30]). However, the study of active learning methodological mixes is beyond the scope of this article. Additional questions address little-studied areas important to instructors such as should active learning methods be more present in online courses, what strategies are perceived as preferrable in optional versus required activities, and just how much weight should active learning methods have in the overall grade in nonproject-based courses?

The specific goals of the study are several. One is a simple comparison of the helpfulness of various different online rehearsal strategies according to the perceptions of students and faculty. Another goal is to compare the perceived importance of study-and-review activities in face-to-face versus online modalities to see if they are more important in one modality than another. An additional goal is comparing the perceived preferences between optional (ungraded) and required (graded) study-and-review activities among students and faculty. A related goal is to compare the amount of formative versus summative assessment preferred by students and faculty in the overall course grade. Logically, one would assume if students and/or faculty prefer student and review activities to be primarily ungraded, then they would prefer more emphasis on summative assessment, and vice versa. A final methodological focus in this study is the divergence of student and faculty perspectives—when they exist—in order to capture their different vantage points.

2. Literature Review

Active learning strategies are used in a wide range of disciplines and course formats. Broadly, research demonstrates that these methods can improve student engagement and achievement. However, active learning approaches are not one-size-fits-all. Their effectiveness varies across educational contexts and by instructor implementation. Understanding students and faculty perceptions of different methods can help clarify when and why certain approaches work best. A review of the literature guided our focus on nine active learning strategies in online courses: practice quizzes, instructor-created study guides, automatically-graded practice problems, synchronous review sessions, laboratory sections in general, student collaboration in labs, small groups during lecture, embedded questions, and polling technologies. Below, we summarize findings from these common strategies, with particular attention to their use in STEM and online contexts. We then discuss how these strategies intersect with assessment practices and how they are experienced by both students and faculty.

Practice quizzes and practice exams are generally found to improve learning achievement [31–33]. However, see Hackathorne and colleagues [34] regarding the lack of improvement in a study using full-scale practice exams. They are particularly helpful in giving students a more realistic view [25,35]. This has been confirmed in STEM settings as well [36]. While agreeing with their overall effectiveness, researchers have noted that students do not do well when they substitute quiz taking for original study [37] and a portion of the students may try to “game the system” and therefore do not improve overall performance [38,39]. That is, students who participate in activities—generally because they get some modest credit for that participation—without doing the accompanying reading and lecture participation tend to learn little because they are essentially shortcutting the input phase of learning.

There are numerous types of *study guides* and their effectiveness (or lack thereof) is based on numerous factors [40]. A study based on requiring textbook guides found that they were effective in improving multiple-choice test taking [41]. A study of medical students found that they were highly effective in focusing student learning [42]. However, Hackathorn, Joyce & Bordieri, [43] questioned the efficacy of instructor-created study guides, perhaps because they are often relatively passive, rather than active, learning tools. In line with this critique, using a concept-based, instructor-designed study guide, Cushen and colleagues [44] found that they encouraged “studying to the test” and actually decreased performance. In a study comparing instructor-designed and student-designed study guides in an active-learning teaching environment, it was found that the two types performed about equally, and substantially better than cases in which there was no study guide [45]. Numerous researchers have pointed out that modern syllabi are more likely to provide detailed information about the course evaluation elements which are functionally equivalent to a study guide, especially in formative assessment activities providing rehearsal or support for the various elements of a project [35,46–48]. Grading rubrics, primarily used for writing assignments and projects, are a study-guide type strategy in helping guide students when they are actively “performing” [49,50]. Despite the fact that they may be construed as passive when they are not well designed, they are included here because the concept is popular with students [51] and when thoughtfully designed, create useful and supportive faculty guidance for student self-interaction, especially when combined with optional or required practice opportunities common in active learning.

While some *automatically scored activities* are a part of the grade (generally on a low-point basis), some are simply provided for practice on an optional basis or as a part of class participation (e.g., identified simply as completed or not completed). While the use of online homework in online classes is nearly ubiquitous, it not necessarily automatically scored [52]. Nearly all studies indicate that homework of some type is very helpful in improving performance because of the error detection and development of self-regulation it provides [53]. While some studies have indicated that online homework can be superior to traditional homework methods [16], other researchers find that the technique used to deliver homework makes minor or little difference in student success [54,55].

Review sessions for exams are certainly popular with many students but we were unsure about whether to include them in active learning strategies. Because Moryl, Gabriele, & Desvira [56, p. 388] made a strong argument that they can be delivered in ways to make them “fun and effective” by using active learning techniques, and Blewett & Kisamore, [57] found interactive, case-based review sessions in medical education to be both effective and justified in terms of instructor time, we decided to err on the side of inclusion. We could not locate any literature focused specifically on the usefulness of *online synchronous review sessions*, pre- or post, but there are a few studies using face-to-face environments. Hackathorne and colleagues [34,43] found students' exam scores were significantly higher for the exams following both a traditional review and a trivia review than for the exam following practice opportunities only. Zhang, Marchong & Li [58] found STEM students significantly enhanced performance after exam review sessions with embedded micro and metacognition strategies. In contrast, other researchers found that between-exam review did not affect re-test performance of medical students in a two-test system [59] nor in an undergraduate economics class [60].

Lab sections have long been de rigueur for most STEM disciplines. Faculty tend to view them as useful for the acquisition of practical skills, equipment familiarity, observational skills, interpretation of data and a critical approach to experimentation, while students tend to see them more as an educational accompaniment to the theoretical knowledge they learn [61]. The difference between instructor and student aims can be an issue when purpose and goals are not clearly explicated [62]. Online lab sessions were frequently thought to be inferior and relatively infrequent in hard science disciplines prior to the COVID pandemic, when rapid transition to online formats was required and numerous issues had to be handled on an emergency basis [21,63–67]. Despite substantial improvements recently in lab technology and pedagogical support, face-to-face labs are often found to be somewhat more effective, especially when familiarity with specific equipment is desirable [68].

A special consideration with labs in courses is whether or not they involve *peer collaboration in labs*. Most studies indicate that working in dyads and triads tends to have significant positive results [64,69,70]. Assigned group work is also associated with increased student motivation and perceptions of belonging in asynchronous online physiology laboratory courses [71]. We reviewed no study that was critical of peer collaboration in labs, so the anticipated issue in our study is how this strategy will compare against other strategies in an online context.

Students can collaborate (outside laboratory sections) as a part of lecture sections or in lieu of them. *Small groups* are a very popular and effective method in non-STEM courses [72] in which learning through discussion is a commonly used strategy. Small groups also have been identified as having potential in STEM face-to-face courses [73]. Small groups have been found efficacious in non-STEM environments in online settings [74–76]. The utility of small groups in lieu of lecture or integrated into STEM courses is less well documented [77,78].

Using lecture-capture and pre-recorded lectures provides flexibility for students and is a popular supplement to course materials but has not generally been found to have a significant impact on learning achievement [79,80]. One study found that lower performing students who relied on recorded lectures, rather than live lectures when they had an option in face-to-face or synchronous courses, experienced poorer performance [81], but another found significant improvement when used as a supplemental strategy [82, 2016]. To promote viewing, engagement and feedback, the *use of embedded questions in lectures* (such as the use of PlayPosit, USATestprep, Edpuzzle, Vudoo and others) in pre-recorded lectures has become a relatively common option. In non-STEM disciplines, studies investigating their effectiveness have yielded mixed results. Some studies have found embedding questions effective [83], while others report marginal or no utility in using embedded questions [84,85]. Most studies in STEM disciplines at both the undergraduate and graduate level report some level of effectiveness in either learning achievement, student satisfaction, and/or error detection [86–89].

Polling technologies can be used in both face-to-face and online modalities. Overall, while polling has not always shown an impact on summative learning achievement, it has consistently been reported to enhance engagement and/or attendance in both non-STEM courses [90–93] and STEM courses [24,94,95]. The use of digital polling in online courses is less studied. Wells [96] recommends its use in higher education, and Bawazeer and colleagues [27] found that polling enhanced performance in a medical education context.

These varied findings motivated us to investigate the comparative value students and faculty give these methods and strategies. Knowing the relative helpfulness of different methods and strategies in an online context is very useful, but it is equally valuable to understand whether students and faculty think they are more important, as important, or less important than in face-to-face courses. If online courses are taught similarly in both contexts, then study-and-review activities should be equally important. One significant difference might be the degree of emphasis on the type of sequential teaching model. In the "traditional" teaching model long, synchronous lectures (either in-person or synchronously online) are combined with simultaneous reading in the first phase of learning. The second phase is primarily rehearsal through out-of-class activities that are optional and unmonitored. In the third phase, the emphasis is on major summative events like tests and papers. Our assumption is that the traditional sequence model still dominates STEM teaching in higher education in the face-to-face mode. In the newer flipped classroom sequence model, in the first phase students listen to condensed lectures in any mode and do simultaneous reading. In the second phase, instructor-monitored activities are done in "class time" from the time "saved" from the condensed lectures. Various study-and-review activities are likely to be substantially more numerous in the flipped classroom model and graded [36,84]. In the final phase, summative assessments occur, but their weighting is significantly reduced. If more coursework is online, and if the flipped model relies more heavily on study-and-review strategies, study-and-review materials may have higher value in online contexts.

An important corollary issue in active learning is the degree to which formative activities—which are largely composed of study-and-review activities—are more-or-less helpful when they are optional as opposed to required assignments. Self-determination theory [97] posits that autonomy is important to learners suggesting the importance of high-quality study-and-review materials, but to what degree does autonomy drive learning in fact-dominated undergraduate courses? For example, Bälter, Enström & Klingenberg [25] found questions with minimal feedback used diagnostically in study-and-review materials still had a significant effect on learning on average. A second major principle of self-determination theory is the belief by the learner that they are achieving competence; however, autonomy and competence sometimes are in tension [98]. How much does the accomplishment of numerous formative assessments build a sense of competence? Some researchers are concerned about grading activities during the learning process because it over-emphasizes rote learning and can potentially stunt long-term learning motivation [99]. Others point to the utility of multiple goals in the learning process by different motivations such as mastery (competence) and grade achievement [100–102]. The literature on self-regulation has also suggested that the higher levels of structure provided by making formative activities required rather than optional is beneficial to learning for weaker students [1]. These mixed findings suggest a delicate balance between offering students autonomy and structure in the learning process. To help clarify these competing goals, our study investigates the perceived value of both graded and optional formative activities.

It has long been observed that assessment can play a positive role in learning but done haphazardly it can hinder learning as well [103]. Assessment theory generally divides assessment into four functions: organizing, motivation, feedback (communication), and evaluation [104]. Assessment can organize the stages of learning before, during and concluding the pedagogic process. It can provide external motivation to perform well. It provides the learner with feedback critical for accelerating learning. Finally, it provides the bases for evaluation. An important issue in assessment theory has been the use and structure of formative evaluation. Organizationally, Butler [31] found that an equivalent amount of repeated testing with reduced study was more effective than prolonged study; Montenegro-Rueda and colleagues [105] had a similar finding in an online context. Numerous researchers have found that reliance on the external motivation that is most prominent in assessment can become dysfunctional if not contextualized and personalized [22,106,107]. Other researchers have found that while the utility of feedback during the formative learning process can be powerful, that power tends to be minimal at the summative stage [19,53]. Similarly, while the evaluation function is powerful as a motivator in the summative stage, evaluation must be used carefully at the formative stage to encourage practice and reflection more than learning "success" per se [16,33,66]. Numerous studies about online courses in higher education have found that formative assessment in the grading mix can play an effective role in learning [72,108,109]. These general findings underscore the importance of varied assessment within course grading structures. However, limited work has examined the balance of formative and summative assessment specifically within online STEM contexts. Students and faculty do not always agree on what constitutes effective learning and assessment. To support mutually positive and productive learning environments, it is valuable to understand if and when student and faculty opinions diverge. As Könings and colleagues point out, "congruent perceptions contribute to optimal teaching–learning processes and help achieving best learning outcomes" and "differences in perceptions deserve detailed attention for optimising learning environments" [110, p. 11]. In a similar vein, Hoy and Weinstein note that "teachers' and students' perspectives are important in every paradigm" [111, p. 191]. Researchers have shared perspectives in many contexts at a general level, but have often found critical contrasts in select aspects of specific settings such as labs [17] and with students of color [112]. Some of the most dramatic contrasts between faculty and student perceptions are reported in online courses. In an important study by Otter and colleagues, they found that "students tend to see online courses as more self-directed and believe that online students must be more willing to teach themselves. Students in online courses feel more disconnected from professors and fellow students than professors believe them to be" [113, p. 27]. Similarly, in another online study it was found that differences between student and faculty perceptions in online courses create barriers that diminish the effectiveness of the teaching-learning environment [114]. Most studies that have investigated both student and faculty perceptions have found their profiles similar, and significant numeric differences (e.g., effect sizes) where they existed to be generally small to modest except in perceived workload issues 1,61,68,92). Building on this work, the present study examines areas of agreement and disagreement between students and faculty perspectives in online STEM contexts.

Finally, several caveats should be noted in interpreting the existing literature. First, teaching effectiveness is generally as much affected by the effectiveness of clusters of complementary strategies as by single a single strategy [26,30,115,116]. However, the study of active learning mixes is beyond the scope of the current study. Second, a variety of strategies may be very helpful in making students with different learning styles and learning situations feel more comfortable. Therefore, less popular strategies may be used as auxiliary tools and be selectively very helpful for some students who need them the most [117,118]. Lastly, positive perceptions of helpfulness do not always translate into demonstrable improvements of summative performance [44,110]. Accordingly, our findings and their implications are intended to be descriptive rather than prescriptive. They provide a broad picture of how students and faculty experience and evaluate active learning strategies in online STEM courses.

2.1. Current Study

This study aims to understand the value of nine active learning strategies in online STEM courses. Previous literature demonstrates the benefits of active learning, yet there is limited knowledge about their use and reception in different course contexts. This study examined five research questions to provide new insights into student and faculty experiences with active learning in STEM:

Research Question 1: In general, which study or review materials are perceived as significantly helpful for learning in online courses?

Research Question 2: How important is it to provide study-and-review materials in online courses compared to face-to-face courses?

Research Question 3a: When instructors provide optional study-and-review materials in online courses, do students usually use them according to student and faculty perceptions?

Research Question 3b: In general, do optional (non-graded) study-and-review activities help students learn in online classes?

Research Question 3c: In general, do required (graded) study-and-review activities help students learn in online courses?

Research Question 4: What percentage of STEM students' grades in online courses should be based on study-and-review activities according to students and faculty?

Research Question 5: Where do STEM faculty and students vary significantly in their perceptions of what is important and helpful in online courses related to the use and implementation of active learning strategies?

3. Methods

3.1. Participants and recruitment

Undergraduate students and faculty from four STEM disciplines were recruited in Spring 2023 from a large public university in the Southwestern United States by a large, funded research team. The four targeted disciplines were computer science, information and decision sciences, mathematics, and psychology. These areas were selected to represent a variety of different fields within STEM that have relatively large student populations at the sampled university. The selection process also prioritized departments that continued to regularly offer online courses post-pandemic. During the data collection period, undergraduate course offerings at this university were 67.2 % face-to-face, 24.8 % fully online, and 8.0 % hybrid format. It should be noted that the sampled university teaches far more introductory and basic courses in an online modality in STEM disciplines, meaning that the student's and faculty's responses are more likely to reflect preferences in survey and basic courses than in advanced level courses.

Students were invited to participate in the survey via their instructors in the targeted departments. The initial dataset was cleaned to remove participants who failed multiple attention checks, submitted duplicate responses, or completed less than 20 % of the questionnaire. In addition, 432 participants were excluded because they reported limited experience taking online STEM classes (0 or 1 online class). The final student sample totaled $N = 727$ undergraduate students who had experience taking multiple online STEM classes. On average, students had taken 4.9 online courses in one of the targeted STEM disciplines (SD = 4.2, range 2 to 60 courses). Demographically, the student sample was majority women (56.1 %), primarily Hispanic/Latino/Latina (63.4 %)—and therefore considered underrepresented minority students, and were typically in their junior (35.4 %) or senior year (52.6 %). It is important to note that students were not asked to reflect on a single course, but their general online experiences.

Faculty were invited to participate in the survey via two or three colleagues in their department. $N = 58$ faculty participants completed the survey (about half of those invited to participate). All faculty participants had experience teaching online or hybrid, with most having taught more than 5 courses and 31.0 % having taught more than 10 courses online or hybrid. Demographically, the faculty sample was majority men (59.6 %), primarily non-URM (56.9 %), and 50.0 % tenure-track with 50.0 % non-tenure track lecturers.

3.2. Questionnaire

A multidimensional questionnaire was designed to understand post-COVID student and faculty experiences and preferences in online STEM courses. The research team identified four areas of focus: Lecture characteristics, rehearsal strategies, testing approaches, and laboratory strategies. These themes capture fundamental attributes in online course design and implementation. A designated subject matter expert (SME) in each theme area was responsible for reviewing recent literature and generating questionnaire items. Each SME ensured that the proposed items reflected current instructional methods in online teaching, with particular attention to techniques that are widely-known and widely-used, yet have limited evidence available about faculty and student experiences. The proposed items were then reviewed and refined by all team members for clarity, content, and relevance across disciplines. Notably, the research team included one to three faculty members from each targeted discipline. The questionnaire was pilot-tested in a sample of 32 students to ensure technical functioning and reasonable completion time.

Items relevant to active learning and rehearsal techniques were the focus of the present work. Most items were measured on a five-point response scale, with a few sliding-scale questions (0 – 100 %). The student and faculty surveys included similar wording. For example, students responded to the prompt "The use of small student groups during synchronous online lectures is important for *my* learning." In some four cases the word "important" was substituted for helpful. Two questions were percentage based. One question about actual usage used the operative word "use" and the question about labs was phrased as "meet learning goals". Faculty responded to a similar prompt but for "*student* learning." See the appendix for the exact wording of the student content questions.

Before the main questionnaire, students were asked to indicate their major and their experience taking online classes. Faculty were asked about their online teaching experience and demographic characteristics. At the end of the questionnaire, student participants were asked about their academic history and demographic characteristics.

4. Results

As indicated by our research questions, the research goals were descriptive in nature. Thus, our analytical strategy emphasized the relative value of different active learning strategies from student and faculty perspectives. Obtaining statistical significance and exact point estimates were not the primary goals. However, inferential statistical tests were used to quantify these comparisons and allow for clearer interpretation of the observed patterns. These tests were conducted using IBM SPSS software version 31.0. The analysis approach treated items as individual measures. There was no factor analysis or scale validation conducted, as the analyses do not presume any latent constructs or composite scales.

The first research question compared the perceived learning value of nine active learning strategies. The top three strategies for students and faculty—over 80 % agreement for one or both groups—were "review-and-study" activities: instructor-created study guides, practice quizzes, and automatically-graded practice problems. Next, there was moderate endorsement for synchronous review sessions, polling during synchronous lectures, and labs in general (more than 60 % agreement for both groups). Students and faculty had mixed views of the remaining three strategies: embedded questions, collaboration in labs, and small student groups. It is noteworthy that eight of nine active learning strategies were found to be valuable for learning by a majority of both students and faculty. However, a minority of students and faculty reported that small student groups are important for learning. Overall, average ratings by students and faculty significantly diverged on three of the nine strategies. Multivariate analyses of variance revealed significant faculty-student differences in perceived helpfulness of the strategies ($F[26, 761] = 6.60$, $p < .001$, $\eta_p^2 = 0.057$). See Table 1 for a graphical summary of the findings for Research Question 1, comparing the perceived helpfulness of various study and review methods.

A similar question asked students to rank which of the four explicit test rehearsal strategies was the most helpful in online courses in their discipline to test for question validity. The profile was similar but the spread among the top strategies was more pronounced. The most popular choice was study guides (46.1 %), followed by practice quizzes (30.2 %). Fewer students selected automatically-graded practice problems (11.1 %) or synchronous review sessions (3.1 %) as their top choice.

Table 1
In general, which study or review materials are perceived as significantly helpful in online courses?.

	% Agree Helpful/ Important for Learning		Mean Difference
Active Learning Practice in Online Classes	Students	Faculty	Sig.
Instructor-created study guides	92.3 %	81.0 %	$p < .001$
Practice/review quizzes	90.8 %	93.1 %	$p = .49$
Auto-graded practice problems	80.2 %	74.1 %	$p = .15$
Synchronous review sessions	68.8 %	79.3 %	$p = .04$
Polls/review questions during synchronous lectures	65.3 %	65.5 %	$p = .76$
Online labs in general	62.1 %	60.7 %	$p = .95$
Embedded questions during recorded lectures	54.7 %	54.4 %	$p = .42$
Student collaboration in online labs	51.4 %	71.4 %	$p = .06$
Small student groups during lecture	28.8 %	43.1 %	$p < .001$

Note. The questions about online labs had a smaller sample ($n = 269$ students; $n = 28$ faculty), as not all respondents had experience taking or teaching online labs. All other questions had a student sample size of 693 to 727 and a faculty sample size of 57 to 58. Mean difference column shows the significance of student-faculty differences in multivariate analyses of variance.

The second research question related to the relative importance of study-and-review materials in online courses compared to face-to-face courses. The most popular response for both students and faculty was "equal importance", by 43.6 % and 57.9 % respectively. Approximately a third of students and faculty thought that study-and-review questions were more important in online courses than in face-to-face classes. Overall, the average rating from students and faculty did not significantly differ, $t(748) = 0.68$, $p = .50$, $d = 0.09$, 95 % CI = [−0.21, 0.42]. See Fig. 1 for a graphical summary of the findings for Research Question 2, comparing differences in perceptions between faculty regarding the comparative importance of study and review materials.

The third research question concerned the use and helpfulness of optional and required study-and-review materials. When asked about usage of optional study-and-review material in online courses, faculty were significantly more pessimistic. While 69.5 % of students agreed/strongly-agreed about student usage, only 52.6 % of faculty agreed. Contrarily, while only 13.8 % of students disagreed/strongly-disagreed about usage, 31.6 % of faculty disagreed. See Fig. 2 for a graphical summary of the findings for Research Question 3, comparing comparative perceptions of student usage of study and review materials.

Students and faculty had similar views about the helpfulness of optional and required study-and-review activities. A slight majority of both students (55.4 %) and faculty (60.4 %) agreed that *optional* study-and-review activities are helpful for learning. Their average response was not significantly different, $t(773) = -0.71$, $p = .48$, $d = 0.10$, 95 % CI = [−0.44, 0.21]. However, both groups more strongly endorsed the value of *required* study-and-review activities, with nearly 80 % of students and 90 % of faculty agreeing. Their average response was significantly different, as faculty agreed more strongly on the helpfulness of required rehearsal techniques, $t(774) = -3.13$, $p = .002$, $d = 0.43$, 95 % CI = [−0.97, −0.15]. Fig. 3 for a graphical summary of the findings for Research Question 1, comparing differences between student and faculty perceptions of study and review activities. .

The fourth research question had to do with the amount of the final grade students and faculty wanted to be comprised of the study-and review activities. On average, faculty reported a preference for a little

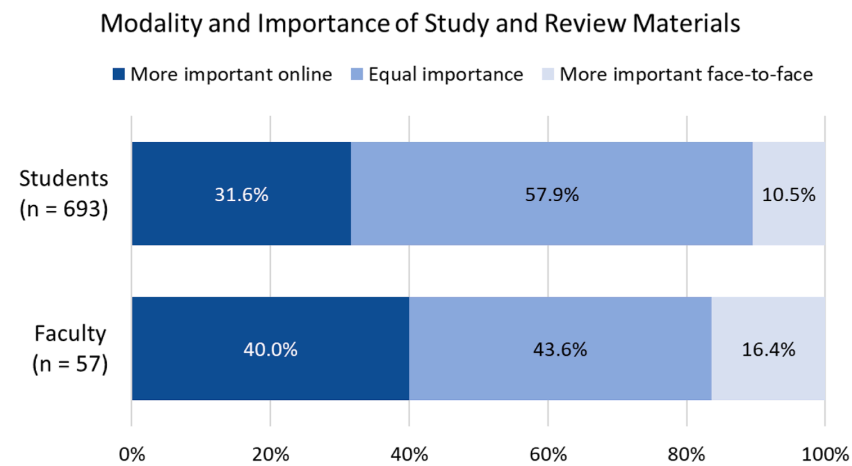

Fig. 1. Modality and Importance of Study and Review Materials.

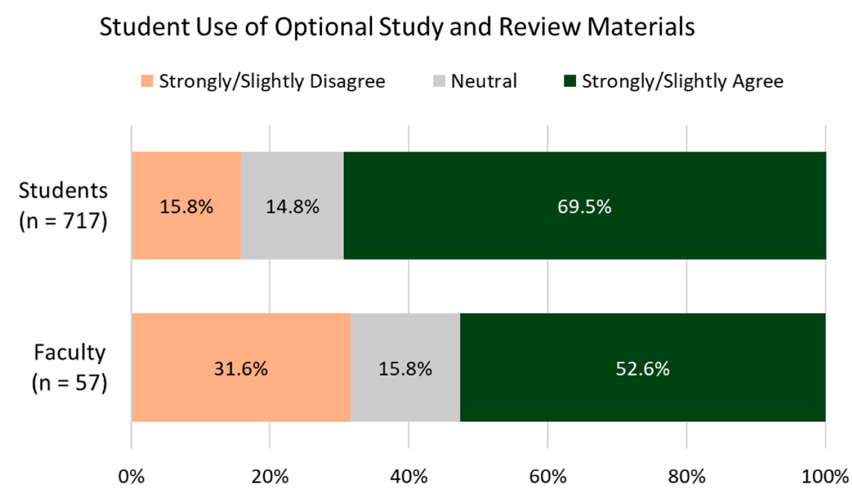

Fig. 2. Student Use of Optional Study and Review Materials.

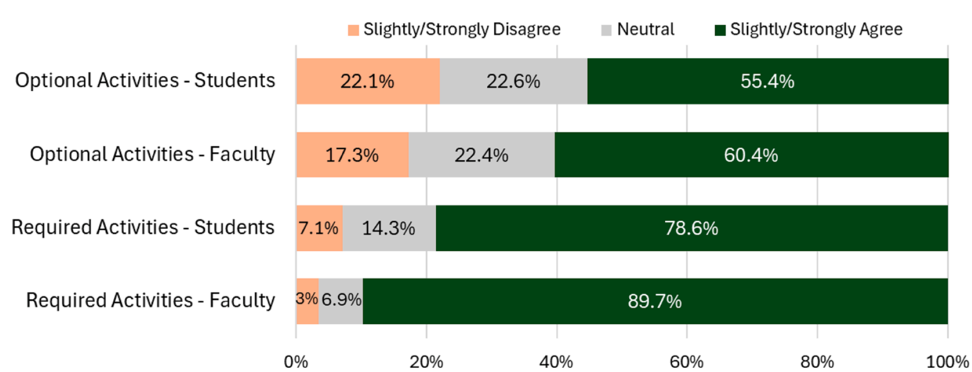

Fig. 3. Perceived Helpfulness of Study-And-Review Activities in Online STEM Courses.

less than a third of the grade (31.8 %) to be based on formative assessment; students wanted about half of their grade (51.6 %) to be based on study-and-review activities, $t(731) = 5.06$, $p < .001$, $d = 0.79$, 95 % CI = [12.12, 27.46]. See Fig. 4 for a graphical summary regarding student and faculty perceptions about their preference for formative versus summative assessments weights in assessment.

The final research question was about where faculty and students vary the most in their perceptions regarding active online learning functionalities in STEM courses. Overall, students and faculty concurred more than not in their estimation of active learning strategies. In four instances the split between students and faculty with regard to concrete strategies was at least 10 %: instructor-created study guides, synchronous review sessions, collaboration in labs, and small groups in lectures. The difference in small groups in lectures was a spread of nearly 15 %. Students were interested in a larger percentage of the course grade being constituted by formative assessments than faculty. Another significant difference was in the use of optional study-and-review materials by students. Faculty were significantly more pessimistic about optional usage. This was also reflected in the increased support—to nearly 90 %—for required study-and-review activities by faculty.

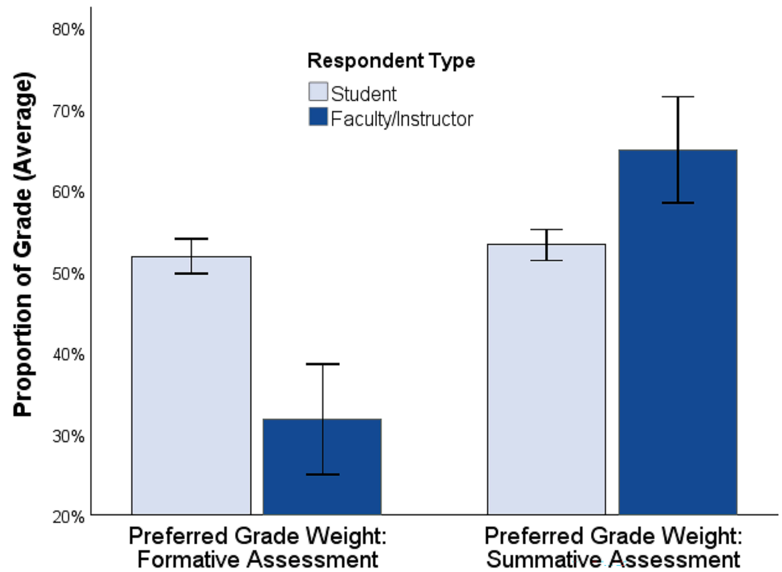

Fig. 4. Preferred Grade Weight by Assessment Type.
Note. Error bars represent 95 % confidence intervals.

5. Discussion

Active learning is important in STEM education. This study looks at the contemporary online context (i.e., after the pandemic) to investigate the degree of perceived importance or helpfulness attributed to different strategies, if study-and-review activities are perceived as more important in online courses than face-to-face, the perceived comparative utility of optional and required study-and-review activities, the perceptions of usefulness of formative assessment in grading, and the comparison the similarities and differences between student and faculty perceptions.

Our findings, based on our working hypotheses, are found in Table 2. Three were fully or largely supported, three were partially supported, and one was not supported. The discussion now focuses on the implications of the findings.

Study-and-review activities may take faculty a lot of time to build and maintain, but both students and faculty understand the importance of them. Instructors should carefully examine the number and mix of them in their STEM courses. While study-and-review activities were perceived slightly more important in online than traditional courses, they are important in both. While faculty are somewhat more dubious about the use of optional study-and-review activities, both students and faculty agree about their helpfulness.

The perceived helpfulness of required study-and-review activities far exceeded our criterion and the perceived importance of optional activities in our population. This important finding suggests that instructors may consider using required, rather than optional study-and-review activities, to constitute the bulk of all such activities. Further, since students in our study wanted to see required activities be an even larger portion of the overall grade than faculty report as average practice, instructors may want to consider if their teaching design can accommodate this preference in their teaching environment.

In sum, there are some concerns about required study-and-review activities circumscribing students' autonomy and creativity. However, these concerns are overwhelmingly countered by the pragmatic interests of students and faculty in the online learning context. In the "average" online course—which is substantially weighted toward introductory and intermediate courses in this survey—students tend to like clear structure, extensive practice opportunities, and prefer their practice be graded. From the qualitative comments received (not reported on here), we hypothesize it is because such practice provides both feedback and an incentive to focus on the learning at hand in a more continuous process rather than focusing on a few, large, anxiety-producing, testing events.

Table 2
Review of the research questions, hypotheses, and findings.

Research question	Hypothesis	Findings
RQ 1	Students and faculty agree that all nine active learning strategies were helpful/important.	*Largely supported.* Eight of nine strategies met the criterion of helpfulness. Small student groups during lecture did not.
RQ 2	Study-and-review materials are more important in online courses compared to face-to-face courses.	*Not supported.* Although students and faculty on average thought study-and-review activities were slightly more helpful, the criterion level was not reached.
RQ 3a	Both students and faculty perceive that students *use* optional study-and-review materials when provided.	*Partially supported.* Students were well over the criterion while faculty were more dubious and somewhat short of the criterion.
RQ 3b	Both students and faculty perceive *optional* study-and-review to be helpful or very helpful.	*Supported.* Both students and faculty found optional study-and-review activities help.
RQ 3c	Both students and faculty perceive *required* study-and-review to be helpful or very helpful.	*Strongly supported.* Both students and faculty overwhelmingly found required study-and-review activities help.
RQ 4	Both students and faculty think that formative assessment should play a larger role in the context of online learning than in most face-to-face courses.	*Partially supported.* Faculty were just shy of the criterion established. Students were far more favorably inclined toward formative assessment being a larger part of their grade than faculty.
RQ 5	The profile of responses for students and faculty are similar.	*Partially supported.* The bulk of the responses by students and faculty were relatively similar. Small statistical significant variance occurred in four of the methods studied. Large differences were evidence in the use of optional study-and-review activities and percentage of the grade that formative assessments should play.

6. Suggestions, Caveats and limitations

While there are no hard-and-fast rules in teaching design, some broad suggestions seem to us obvious and widely applicable. First, multiple active learning strategies should generally be integrated into all online STEM courses. Second, those strategies should include a mix of learning engagement activities (e.g., questions embedded in recorded lectures and polling in synchronous lectures) and test-focused activities (e.g., practice quizzes and instructor-created study guides). Third, in online STEM courses instructors may consider making a range of formative assessment activities a substantial amount of the overall grade, depending on their context and student expectations. Fourth, while optional study-and-review materials may not be as utilized or helpful, they can supplement graded study-and-review materials when possible for optimal universal design learning. Fifth, because active learning strategies often take time and energy to build and maintain, instructors should consider adding them and rotationally updating them over multiple terms.

This study focuses on and compares perceptions of importance and helpfulness of online learning strategies. Perceptions are closely aligned with teaching/learning satisfaction and comfort, but sometimes not as closely aligned with learning performance. Two examples are particularly relevant in this regard. The literature indicates that students like study guides that are closely tailored to the exam in order to limit the range of studying they are required to do. Faculty, on the other hand, tend to see study guides as organizers for students and overarching reviews. Therefore, faculty can supply what they think students want and yet students still may not be content. A second example is small groups during or in-lieu-of some lecture time. Social sciences, humanities and some professional education disciplines that do not have labs recommend the integration of small group activities for both the purpose of active and communal learning purposes. However, while STEM faculty may follow the lead of the broader literature on the need for and success of small group learning, STEM students seem to indicate that such activities must be selectively utilized in an already active-learning-rich environment with labs.

Finally, there are a number of limitations to and boundary conditions for this study that should be noted. The study comes from a single institution which is highly diverse and therefore may have less generalizability to different types of higher education institutions (e.g., elite institutions). For simplicity, the study focuses on comparing individual active learning strategies, but ultimately instructors use complementary clusters of methods. As noted, perceptions of teaching and learning importance and helpfulness (by both students and faculty) are not always aligned with actual learning performance. The disciplines—mathematics, psychology, information and decision science, and computer science—are all NSF designated STEM disciplines but omit the hard and health sciences. While the student population sampled is generally very large (i.e., 1256), the faculty sample is modest. Because the study strives to get macro level perceptions of nine methods, we do not seek to differentiate usage in different online modalities; fully synchronous courses may display a somewhat different profile (although they are much less common in STEM teaching). The inclusion of instructor-created study guides may not fit all researchers' definition of an active learning method in that it only supports active learning rather being an active learning technique in-and-of-itself. A reviewer rightly pointed out that while we included a question on auto-graded practice problems, we did not include a question on instructor-graded practice problems which are especially important in complex exercises with variable solutions. (We did include a question on online labs which is a common source of active learning in STEM courses and we explicitly excluded term papers and projects outside of labs for investigation in this study). Despite these limitations, we believe that the present study gives a much clearer picture of student and faculty perceptions in a post-COVID context with regard to the importance of active learning methods and their inclusion as a part of the final grade in online STEM courses.

CRediT authorship contribution statement

Montgomery Van Wart: Writing – original draft. **Mirand McIntyre:** Methodology. **Jing Zhang:** Writing – review & editing. **Pamela Medina:** Writing – review & editing. **Anna Ni:** Writing – review & editing. **Lewis Njualem:** Investigation, Data curation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Anna Ni reports financial support was provided by National Science Foundation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix: Content. Questions Related to this Study (Student Version)

1. Practice quizzes and/or review quizzes help me learn in online [discipline] courses.
2. Instructor-created study guides help me learn in online [discipline] courses.
3. Automatically-graded practice problems help me learn in online [discipline] courses.
4. Synchronous review sessions help me learn in online [discipline] courses.
5. Online [labs] help me meet course learning goals.
6. Working together with other students is helpful for completing online [discipline] lab activities and assignments.
7. The use of small student groups (for example, breakout rooms in Zoom) during synchronous online lectures is important for my learning.
8. The use of embedded questions during lecture recordings is important for my learning. ("Embedded questions" means the video occasionally pauses for students to answer questions about the video.)
9. The use of polls or review questions during synchronous online lectures is important for my learning.
10. How important are instructor-provided study-and-review materials in online [discipline] courses compared to face-to-face courses?
11. When instructors provide optional study-and-review material in online [discipline] courses, I usually use them.
12. In general, optional (non-graded) study-and-review activities help me learn in online [discipline] courses.
13. In general, required (graded) study-and-review activities help me learn in online [discipline] courses.
14. In your opinion, what percent of your grade in online [discipline] courses should be based on study-and-review activities? (For example: practice quizzes, lecture video questions, automatically-graded homework problems, etc.)
15. In your opinion, what percent of your grade in online [discipline] courses should be based on formal activities demonstrating what you have learned? (For example, exams, projects, written assignments, etc.)

Survey questionnaire notes: The parenthetical material was presented to students as presented here. The bracketed material changed according to the student's major and the brackets themselves did not appear.

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