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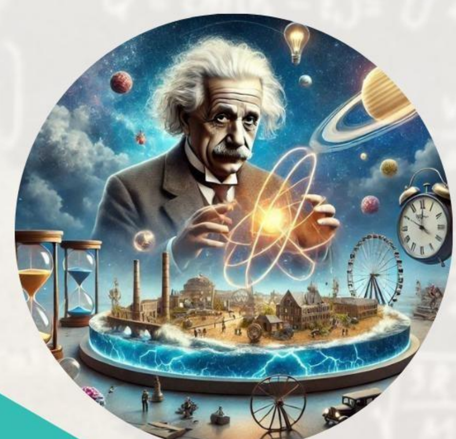

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A Review of Research on the Impact of Active Learning Strategies on the STEM (Science, Technology, Engineering, and Mathematics) Academic Performance of Asian Students

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Abstract

The goal of this research is to compile all available information on how active learning impacts the STEM (science, technology, engineering, and mathematics) performance of Asian students. This extensive meta-analysis study examines the effects of different active learning approaches and instructional methods on the performance of Asian students in STEM-related subjects. The approaches include discovery-based, problem-based, collaborative, experiential, and activity-based learning. We used search keywords and dates to search the Scopus electronic bibliographic database for relevant papers that fulfilled our inclusion criteria. Asian students' exposure to any active learning intervention in STEM-related courses was a primary requirement for research to be included in this meta-analysis. Research studies were evaluated when they met the inclusion criteria. in order to retrieve info. A meta-analysis was conducted using 2810 full-text peer-reviewed studies published between 2000 and 2020, with 38 of those papers meeting the inclusion criteria. A thorough and systematic evaluation was conducted utilizing the gathered data to determine effect sizes between the experimental (n = 2230) and control (n = 2510) groups. The data was analyzed using means and standard deviations. A effect size of 0.6596 was found using the study means and standard deviations, which is considered pretty substantial. A much larger mean impact size was found when comparing pre- and post-test results, suggesting that active learning improved the STEM performance of Asian students. Based on the results of the meta-analysis, this research sheds light on how active learning impacts the STEM performance of Asian students. Lastly, we talk about how these results are important and relevant to where the study should go from here.

Keywords Active learning · Control group · Effect-size · Experimental group · Lecture-based · Meta-analysis · STEM · Student performance

Introduction

Active learning environments that place students at the center have gained prominence in the last ten years in the world of higher education. In these settings, students apply their conceptual knowledge and higher-order thinking skills to the learning process, and they eventually learn to take responsibility of their own learning (Ting et al., 2019; Trinidad, 2019). According to Machemer & Crawford (2007), Ng et al. (2020), and Ní Raghallaigh & Cun- niffe (2013), active learning is founded on reinforcing higher-order thinking skills like critical analysis, synthesis, and evaluation, which necessitate that learners actively participate in their learning instead of merely receiving instruction passively. Bonwell and Sutherland (1996), Kim et al. (2013), and Love et al. (2014) are just a few of the educational domains that have made use of the active learning method, which aims to shift students' learning styles from passive to active in order to increase engagement and interaction among learners. The qualities and nature of active learning methodologies may be seen differently in other cultures, particularly in an Asian environment, due to their origins and conformity with western background and culture. Take active learning as an example. It challenges the conventional reticent attitude often seen in Asian classrooms by promoting active involvement, engagement, and interaction as essential components of education.

For example, Yoder and Hochevar (2005), Armbruster et al. (2009), Ballen et al. (2017), and Freeman et al. (2007) have all looked at how active learning impacts student performance in many fields. Noteworthy among these studies is a meta-analysis of 225 papers by Freeman et al. (2014), which compared the effectiveness of active learning strategies with more conventional lecture-based methods of teaching undergraduates STEM subjects, including test scores and failure rates. Students' performance on examinations and concept tests improved by 0.47 standard deviations when active learning methods were used, in contrast to the increased failure risk associated with the conventional lecture-based method (Freeman et al., 2014). The results of their research showed that the active learning scenarios resulted in a 6% improvement in mean test scores (Freeman et al., 2014). These findings also provide credence to the present

Using active learning strategies in STEM fields, it also acts as a rallying cry for STEM teachers to up their active learning game in STEM-related classes. The meta-analysis conducted by Freeman et al. (2014) yielded satisfactory data and valid findings that suggest active learning improves student performance across disciplines. Specifically, it found that undergraduate STEM students' academic performance was objectively enhanced through active learning compared to a traditional lecture-based format. While the results did show that active learning improved performance, there are still many questions about the effect and significance of active learning, particularly in relation to Asian students' performance in STEM-related courses, and these results may only apply to Western contexts. Hence, this study aims to fill this knowledge gap in the current literature by conducting a meta-analysis of published data on the impact of active learning on the performance of Asian students in STEM subjects. The data will be drawn from all Asian studies that meet our inclusion criteria for active learning in STEM subjects. Although many studies have looked at how different active learning strategies affected students' performance in STEM classes throughout Asia, no one study has looked at the efficacy of active learning in STEM classes in Asia as a whole. The purpose of this study is to find out whether Asian students do better in undergraduate STEM classes when teachers use active learning strategies instead of the tried-and-true lecture method. We plan to use meta-analytic techniques to draw our conclusions. Learning gain, or the difference between two measures of real student performance (such as a positive difference in students' posttest and pretest examination scores, for objective performance, or learning satisfaction, for subjective performance), is used to define performance in this study.

Theoretical Background

Active Learning

In the active learning paradigm, students take an active role in their own education by practicing and refining higher-order cognitive abilities that facilitate in-depth comprehension and learning (Shroff et al., 2021). Nicol et al. (2018) state that active learning encompasses a wide range of various instructional techniques and approaches to teaching and learning. This goal has motivated a number of initiatives to revamp the conventional lecture format. class pedagogy through the use of active learning strategies, methods, and pedagogies like collaboration, experiential learning, discovery-based, group-inquiry-based, problem-based, and activity-based learning. These approaches are learner-centered and aim to engage students and apply skills like critical thinking, knowledge construction, and real-world problem-solving (Herreid & Schiller, 2013; Wright et al., 2019).

Rather than relying on traditional lecture-based pedagogy or passive learning strategies, this study employs an operational definition of active learning that encourages student participation in class as a means of facilitating their own learning (Shroff et al., 2021; Ting et al., 2019).

Active Learning on Student Performance

Evidence from a variety of sources suggests that active learning improves students' performance in the classroom, both in terms of grades and other quantitative measures and in terms of more abstract abilities like the capacity to think critically and creatively (Burt, 2004; Eichler & Peeples, 2016; Freeman et al., 2007; Yuretich et al., 2001). As the first and most thorough meta-analysis to date with the most included publications concerning the impact of active learning variations on student performance metrics, Freeman et al. (2014) study continues to rank among the most referenced scientific articles. Students in STEM subjects performed better in active learning environments, according to a well-designed meta-analysis by Free-man (2014). In contrast, students in traditional lecture-based classrooms had a 1.5-fold higher failure rate compared to those in active learning environments. The odds ratio for failing in the traditional setting was 1.95. Active learning significantly improved academic achievement, especially in smaller courses with fewer than fifty students, according to the same research (Free-man et al., 2014). Not only that, but research by Armbruster et al. (2009) showed that incorporating active learning into course design significantly improved student attitudes and performance. Additionally, a research done by Burt (2004) shown that active learning may greatly enhance students' academic performance and accomplishment when moving away from the conventional lecture-based approach to education. Despite the abundance of research on the impact of individual active learning strategies on STEM students' performance in Asian classrooms, no comprehensive meta-analysis has yet assessed the efficacy of active learning as a whole in the region. With the use of impact size calculations and statistical analyses, this research will try to figure out how

impact Asian students and show policymakers and educators whether active learning accomplishes the aims of effective education in an Asian setting.

Active Learning Within an Asian Context

As active learning modes of instruction become more widely accepted in STEM-related subjects and disciplines, it is also imperative to evaluate whether culture plays a role in the effectiveness and types of outcomes that can be expected, specifically in the context of Asian classroom settings (Cam- baliza et al., 2004). Traditionally, in an Asian context and often regardless of subject or discipline, common instruc- tional teaching methods have typically included a didactic lecture-based pedagogy with highly structured learning activities that require strong instructor-centered control, comprising of drill-and-practice exercises with a high dependence upon facts, rote learning and other passive forms of learning (Carr et al., 2015; Tuyết, 2013a, b; Wong, 2004). However, we are now beginning to see a clear shift away from the traditional instructor-centered and passive learn- ing delivery models that characterises Asian classrooms to more active learning student-centered approaches that fos- ter deeper learning and allow students to engage, interact and collaborate with their peers (Cambaliza et al., 2004; Sivan et al., 2000). Moreover, recent research has shown that group-based and collaborative instructional activities fit with an Asian culture with emphasis on collectivistic orientation and cooperation over competition and a strong emphasis on achievement and mastery of skills (Frambach et al., 2014; Lee & Yang, 2020; Wahono et al., 2020). Furthermore, numerous studies of various types have examined the impact of active learning within Asian contexts (Cambaliza et al., 2004; Ng et al., 2020; Park & Choi, 2014; Ting et al., 2019).

Rationale for a Meta-analysis

There are a number of reasons why this research opted for a meta-analysis technique. First, the current meta-analysis by Freeman et al. (2014), which compared active-learning with conventional lecture-based teaching in North American contexts, is the primary source of inspiration for our work. To thoroughly investigate the current state of research on active learning, especially as it pertains to the performance of Asian students in STEM-related courses, we believe a meta-analysis is warranted. As a second point, a more precise description and illustration of the characteristics of the impacts of active learning on the performance of Asian students in STEM courses may be achieved by doing a systematic evaluation of current research. This would also enable us to concentrate on the effect size across studies. The third way is to do a systematic review by collecting and analyzing all public data (i.e., quantifying by pooling the findings of several research and determining the impact size of each one, we could then get a total effect size from all of them. Lastly, by combining and accurately assessing all of the research, a meta-analysis would provide us a more quantitative and statistically grounded result by considering the strength of impact size in each empirical study reviewed.

Methodology

Criteria for Inclusion and Exclusion

Explicit criteria for inclusion and exclusion were established before reviewing the literature to ensure the relevance of the selected full text published research papers extracted from the bibliometric database. For the present study, the follow- ing inclusion criteria were applied to the studies extracted by the literature search: (1) research subjects were primary, secondary, tertiary or vocational students at the time of the study; (2) studies that explicitly investigated the effects of active learning interventions on student performance in a STEM-related discipline; (3) studies from Asian countries;
(4) studies that implemented an intervention that involved an active learning pedagogy, strategy or treatment; (5) studies that included at least two treatment groups: an experimental group that were treated with the active learning pedagogy and a control group that either experienced a traditional lecture-based treatment or an active learning approach treat- ment; (6) the research recorded a quantitative measure of academic student performance, including average mean, standard deviation and sample size for both groups; (7) the research provided the necessary statistical information for the calculation of effect sizes; and (8) Searches were restricted to English research articles. Criteria for exclu- sion included: (1) studies published that are not available electronically; (2) studies providing qualitative analysis and evaluation only; (3) non-English studies; (4) abstracts and review papers; (5) studies with methodological shortcom- ings and deficiencies such as non-randomized controlled tri- als; (6) studies with incomplete data; and (7) studies that did not calculate or present data on means, standard deviations, sample sizes, etc.

Data Collection

The data collection procedure comprised of rigorously and systematically locating all relevant empirical Asian stud- ies related to active leaning interventions on student per- formance in STEM-related disciplines. The inclusion of all possible studies, which met the criteria, constituted a more comprehensive and representative sample of all studies published. For this study, a computer-based literature search of the Scopus bibliometric database was used for bibliometric analysis, allowing for enhanced literature search capabil- ity. Scopus was chosen as a bibliometric source because of its extensive coverage of peer reviewed education literature including a more expanded variety of academic journals in the science, technology, medicine, natural science and social sciences field. Moreover, Scopus was selected for this study because of its unique functionalities that allowed us to per- form a more comprehensive search using specific keywords in order to generate a more defined query for obtaining the relevant bibliometric data. This included searching and identifying main keywords in the Publication Date, Title, Abstract, Document Title, Type of Document, Journal Name and References fields. The selection of keywords in the Scopus database was critical to our meta-analytic analysis since the keywords directly influenced the amount of data that was retrieved. Different active learning pedagogies and treatments were extracted from those included in Freeman's meta-analysis, and keywords were used in a comprehensive search for titles and abstracts in Scopus to narrow down literature related to active learning.

For our meta-analysis, a search in Scopus was per- formed using a combination of search terms, search que- ries and exclusion criteria with a combination of "AND"-, "OR"- and "'NOT" Boolean search operations to ensure the retrievals or outputs were precise. Since active learning is an umbrella term that encompasses a range of different pedagogical methods, our search strategy comprised of a keyword search of "active learning" as well as numerous search terms relevant to active learning, both in the title and abstract fields on the Scopus database. A literature search using Scopus was performed for journal articles published from 2000 through 2020, which included broad and narrow variations of instructional approaches related to active learn- ing (for example, collaborative learning, experiential learn- ing, discovery-based, group-inquiry-based, problem-based, activity-based learning, etc.) were searched (see Table 1).

Moreover, search terms were combined with "Asia" and each individual country (for example, "Afghanistan", China", "India", "Mongolia", etc.) in the title, abstract, or list of subject heading terms, limited to English. For exam- ple, the search criteria in Scopus was performed by search- ing for terms or term combinations and/or by generating the filtered keywords out of papers and articles. For example, the search criteria in Scopus was performed by searching for terms or term combinations and/or by generating the follow- ing filtered keywords out of papers and articles:

Table 1 Search terminology of instructional approaches related to active learning

Active learning	Flipped learning/flipped approach	Project oriented learning
Action learning	Generative learning	Question-based learning
Action-oriented learning	Goal-based learning	Reflective learning
Anchored instruction	Group learning	Resource-based learning
Authentic learning	Group-inquiry-based learning	Role-play-based learning
Active engagement	Inquiry learning	Scenario-based learning
Activity-based learning	Inquiry-based learning	Self-directed learning
Case method	Inquiry-guided learning	Self-regulated learning
Case-based learning	Interactive learning	Service learning
Collaborative learning	Interprofessional learning	Simulated learning/simulation-based learning
Cooperative learning	Learner-centered learning	Situated learning/situational learning
Competency based learning	Mastery learning	Social learning
Computer-assisted learning	Mobile learning	Student-centered learning
Concept-based learning	Peer-assisted learning	Task-based learning
Context-aware learning	Peer-assessed learning	Task-oriented learning
Context based learning	Peer-to-peer learning	Task-based interaction
Discovery learning	Performance-based learning	Team-based learning
Discovery-based learning	Peer instruction	Think-pair-share
Expansive learning	Practice-based learning	Transformative learning
Experiential learning	Problem-based learning	Transformational learning
Experimental learning	Problem-orientated learning	Work-based learning

Evidence based learning	Project-based learning

LIMIT-TO (EXACTKEYWORD, "ACTIVE LEARNING", "MEAN" "STANDARD DEVIATION") AND (LIMIT-TO (AFFILCOUNTRY, "China") AND SRCTYPE(j) AND (LIMIT-TO (LANGUAGE,"English"). Scopus searches could only include topics within the following STEM and STEM-related fields. "COMP" (COMPUTER SCIENCE) "ENGI" (ENGI- NEERING) "MEDI" (MEDICINE) "PHYS" (PHYS- ICS AND ASTRONOMY) "MATH" (MATHEMATICS) "DECI" (DECISION SCIENCES) "BIOC" (BIOCHEM- ISTRY, GENETICS AND MOLECULAR BIOLOGY) "ENVI" (ENVIRONMENTAL SCIENCE) "MATE" (MATERIALS SCIENCE) "AGRI" (AGRICULTURAL AND BIOLOGICAL SCIENCES) "NURS" (NURSING) "ENER" (ENERGY) "EART" (EARTH AND PLAN- ETARY SCIENCES) "MULT" (MULTIDISCIPLINARY) "PHAR" (PHARMACOLOGY, TOXICOLOGY AND PHARMACEUTICS) "HEAL" (HEALTH PROFESSIONS) "CENG" (CHEMICAL ENGINEERING) "DENT" (DEN- TISTRY) "IMMU" (IMMUNOLOGY AND MICROBIOL- OGY) "VETE" (VETERINARY)

As shown above, 12,187 titles were produced by the first computer search that used a mix of search phrases and Boolean operators. The list was further narrowed down to 28,10 publications after each study's relevancy was evaluated based on its title and abstract. These articles could be sifted using these two terms as they were obliged to disclose both the mean and standard deviation on student academic performance according to the inclusion criterion (6) outlined earlier. In order to automatically scan texts and return the number of occurrences of a term in each page, an algorithm was created using the JavaScript programming language and then a sequence of instructions performed in JavaScript. Figure 1 is a flow diagram depicting the results of the electronic search. It consists of four phases that summarize the selection process.

We retrieved the 2810 publications that were accessible for download and uploaded them to a server. Then, we applied the algorithm to the key terms "mean" and "standard deviation." Additional reductions to 585 relevant research publications occurred as a result of the algorithm's predetermined elimination of studies without either word or quantitative analysis necessary to determine impact magnitude. A member of the research team read each manuscript in the remaining 585 studies; each author was given a collection of around 116 papers to review. The abstract was reviewed to ensure it met the required standards. Some studies were not included because they did not address pedagogy, science, technology, engineering, or mathematics (STEM) education, did not provide a control group comparison, or focused on perception rather than academic achievement. The result was a reduction in the number of articles from 44 to 38, representing a significant reduction. That ought to be

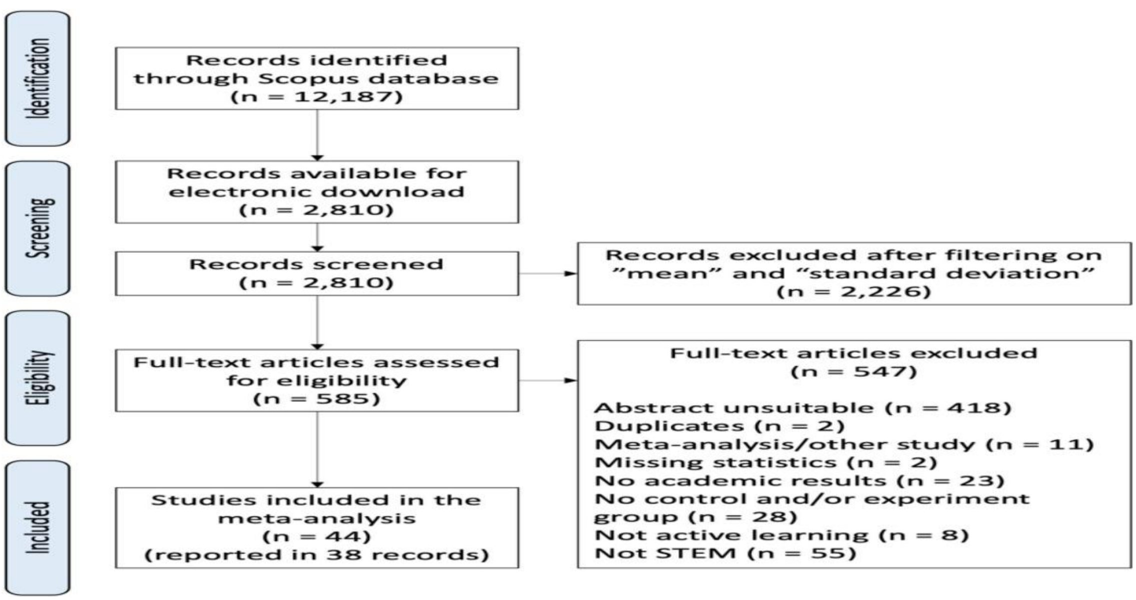

Fig. 1 Flow diagram of the selection process

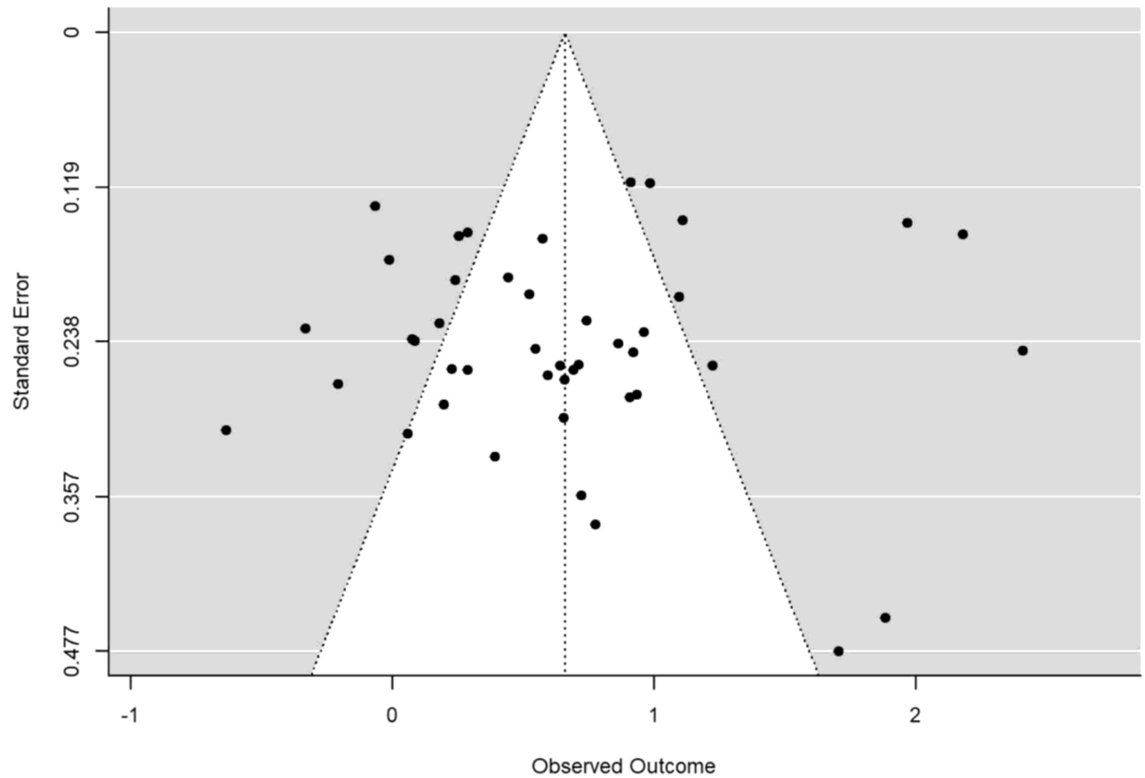

Fig. 2 Funnel plot demonstrating no publication bias

Table 2 Moderator analysis: country/region

Country/region	Effect size	SE	*Z*-value	*p*-value	Confidence interval	*Q*	df	*p*
Intercept (China as base)	0.287	0.593	0.484	0.628	(−0.875, 1.449)	11.034	9	0.273
Hong Kong	−0.24	0.697	−0.344	0.73	(−1.606, 1.126)			
India	0.298	0.645	0.462	0.644	(−0.965, 1.561)			
Indonesia	0.975	0.687	1.419	0.156	(−0.372, 2.322)			
Korea	0.126	0.726	0.173	0.863	(−1.298, 1.549)			
Malaysia	0.261	0.747	0.349	0.727	(−1.204, 1.725)			
Singapore	−0.002	0.864	−0.002	0.998	(−1.695, 1.692)			
South Korea	−0.267	0.739	−0.362	0.718	(−1.715, 1.18)			
Taiwan	0.528	0.607	0.869	0.385	(−0.662, 1.718)			
Thailand	−0.062	0.864	−0.072	0.942	(−1.755, 1.631)			

Table 3 Moderator analysis: discipline category

Discipline category	Effect size	SE	*Z*-value	*p*-value	Confidence interval	*Q*	df	*p*
Intercept (Engineering as base)	0.872	0.206	4.234	< .001	(0.468, 1.275)*	2.972	4	0.563
IT and Computer Science	−0.189	0.291	−0.649	0.517	(−0.76, 0.382)			
Life Sciences	−0.244	0.337	−0.725	0.468	(−0.904, 0.416)			
Mathematics	−0.652	0.382	−1.705	0.088	(−1.401, 0.098)			
Sciences	−0.237	0.269	−0.881	0.378	(−0.765, 0.29)			

different STEM discipline categories present in the studies yielded in the meta-analysis.

Discussion and Conclusion

Active learning's impact on Asian students' performance in STEM courses has been the focus of several research published in scholarly publications between 2000 and 2020. This meta-analysis aims to synthesize and examine these results in a quantitative manner. Despite mounting evidence of active learning pedagogies' positive effects on students' academic performance in Western contexts, it is crucial to examine whether or not such approaches work in other cultures (Frambach et al., 2014). Based on the results of this study, active learning has a substantial positive influence on Asian contexts. This suggests that active learning pedagogies can effectively bridge the gap between Western and Asian cultures, which provides more evidence in favor of implementing active learning policies in Asian nations. Not only does our study's effect size align well with Freeman's (2014) meta-analysis, but our findings also indicate a stronger influence in Asian environments. With an effect size of 0.47, Freeman's findings demonstrated a moderate preference for active learning. Also worth mentioning is that Freeman's findings were in line with earlier meta-analyses on non-traditional teaching methods that reported impact sizes of 0.5 and 0.51, respectively (Ruiz-Primo et al., 2011; Springer et al., 1999). These findings demonstrate that a half-standard-deviation improvement in student performance is possible as a consequence of improvements in Western pedagogies. With an impact size of 0.6596, our study surpasses the designated medium effect size and shows an improvement over the prior medium classifications seen in Western context studies. Student performance improved by two-thirds of a standard deviation in Asian environments, compared to half a standard deviation in Western situations, as shown by this substantial impact size. As a result, as compared to a class that does not use active teaching pedagogies, Asian students' assessment performance scores improve by over 10%, assuming a similar or greater standard deviation of assessment marks as in Free-man's (2014) meta-analysis.

What follows is a list of possible explanations that might shed light on the apparent academic advantage enjoyed by Asian pupils over their supposedly "Western" peers. Carr et al. (2015) and Tuyết (2013)a, b found that in Asian contexts, the formal traditional lecture delivery is often instructor-centered and content-oriented, with learners being treated as passive receivers of information rather than active and engaged participants in the learning process. It was Wong in 2004. As a result of actively engaging in a new learning activity, Asian students become totally involved and find learning meaningful when the typical lecture style is changed from being static, didactic, and almost suppressed to being learner-centered, inquiry-based, and collaborative. By participating in learning tasks and activities that inspire them to learn, both individually and in groups with their teachers and classmates, students develop an innate interest for and enthusiasm for the learning process, which has a direct correlation to their academic success. Secondly, this active learning strategy may have a bigger and more noticeable impact on Asian students than on Western students in general, as active learning interventions represent a big change and new choice for Asian students compared to their Western classmates. Last but not least, superior academic achievement, deeper learning, and higher-order thinking skills are the end benefits of this active learning instructional technique as compared to the passive and rote learning method.

Although this meta-analysis did uncover some promising results, it is important to note that the study did have several limitations. research that show statistical significance, or evidence that supports a desired effect, are more likely to be published, which might lead to publication bias in meta-analysis of published research. Results should be taken with caution, notwithstanding the visual examination of publication bias using a funnel plot and asymmetry test. Another caveat is the possibility of heterogeneity among the research, which arises from the fact that all of the chosen studies were conducted in Asia. This might mean that there are variations in study designs, participants, demographics, and results across the studies that were considered. Students' performance may be even better if active learning pedagogies were to undergo improvements and innovations (Freeman et al., 2014).

Considering the heterogeneity of the studies, we can delve deeper into the results of the moderator analysis to explore potential differences in the impact of active learning within two specific boundaries: (1) the Asian region and (2) STEM discipline categories. To start, there is no statistically significant difference in the impact magnitude by nation or location. Comboliza et al. (2004), Ng et al. (2020), Park and Choi (2014), and Ting et al. (2019) are only a few of the research that have shown the beneficial effects of active learning across cultures in geographically adjacent areas of both developing and developed Asian countries. The present state of education and pedagogy throughout Asia is shaped by a variety of cultures and traditions, yet it is comparable enough that introducing and implementing active learning methodologies yields comparable beneficial results.

effects. Given the limits of this study, it would be beneficial to do more research to see whether bigger samples do reveal any significant differences. If this is the case, it might provide local educators and lawmakers with more information about which people can benefit greatly from active learning methodologies and assist pinpoint the possible factors that lead to increased impacts of active learning.

Similarly, when active learning methodologies are applied to several STEM fields, little variance is seen. Because of this, the vast array of STEM subjects may benefit from the positive and substantial enhancement of active learning that this meta-analysis finds. Further research within the specific STEM subjects may still produce intriguing results regarding the impact of active learning pedagogies; however, it should be noted that STEM, in its broadest sense, encompasses a variety of strong practical application skills and theoretical reasoning.

Several avenues might be explored, circling back to the present focus of our meta-analysis. For instance, building on this study in the future may include investigating how different learning environments, such blended and face-to-face learning, affect student engagement and motivation. A meta-analysis of research on active learning in more narrow settings, like when students use technology to supplement their education, could be another avenue for future investigation. Such a study could examine the correlation between technology-enabled active learning environments, student achievement, and the acquisition of higher-level skills. Lastly, the results of this research

have important research, practical, and practical implications for STEM classes taught at the university level, particularly for the ways in which different active learning strategies might be used to boost student achievement.

In conclusion, this research lays the groundwork for a future systematic and meta-analytic evaluation of active learning's impact on Asian students' STEM achievement. Numerous variables, such as changes in educational policy, the proliferation of online and remote learning, and access to technology advancements, are impacting the educational landscape in Asia, both in the near and far future. A radical departure from the status quo of lecture-based, passive learning approaches is urgently required in light of these new realities. This meta-analysis study's findings support the idea that Asian students can benefit greatly from adopting active learning strategies in STEM classrooms. It therefore calls for a rethinking of current approaches to STEM education and calls for more research into the efficacy of these methods in other settings.

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Thanks!