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The Effectiveness of Evidence-Based Teaching Practices in Biomedical Sciences on Students' Learning Experience: A Systematic Literature Review

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Abstract
The traditional didactic approach to teaching in biomedical sciences falls short of providing students with the 21st century competencies necessary to meet the socioeconomic demands placed upon them. Tertiary biomedical science educators have sought empirical evidence to identify the best practices to meet these demands, each of which have an element of actively involving students in their learning, as opposed to passive and didactic instructional approaches. This review synthesises the literature on evidence-based teaching practices (EBTPs) implemented in biomedical science disciplines and investigates the impact of EBTPs on students' learning experiences through a systematic review. Seventy-eight studies were analysed, providing a comprehensive review of teaching practices that supported active learning in biomedical science disciplines. The findings revealed that EBTPs had significant impact on students' academic performance and learning experiences to enhance higher-order thinking skills and self-directed learning, despite the variation in educational setting. A range of instructional strategies and technologies that supported active learning experiences were identified in this review, and the findings provide an evidence base to inform pedagogical decisions regarding the implementation of EBTPs and may serve as an impetus for instructors to implement active learning strategies based on this empirical evidence.

Introduction

Evidence-based teaching practices (EBTPs) are instructional practices based on empirical evidence and encompass a variety of pedagogies that range from social-constructivist learning to personalised learning, enhance active learning, and are based on student-centred learning approaches (Frost et al., 2018; Soto, 2020). Some researchers classify teaching approaches across three dimensions of teachers' instructional practice: cognitive activation, classroom management, and providing student learning support (Depaepe & König, 2018; Voss, Kunter, & Baumert, 2011). *Cognitive activation* refers to instructional practices that enhance students' learning. *Classroom management* denotes instructional practices that encompass classroom time management and student behaviour. *Student support* addresses the provision of encouragement and adaptive learning support. Voss et al. (2011) emphasised that instructors' use of teaching practices should be based on knowledge of classroom management, teaching methods, classroom assessment, and student heterogeneity. Other researchers posit that instructional practices should incorporate active learning strategies, formative and summative assessment approaches, inclusive teaching practices, reflective practices, group discussions, and practices that provide clarity around learning objectives and expectations (Bathgate et al., 2019; Wieman & Gilbert, 2014).

Many educators in the biomedical sciences emphasise the use of student-centred active learning approaches (Colthorpe, Zimbardi, Bugarcic, & Smith, 2015; Jumah & Ruland, 2015; Kim, Speed, & Macaulay, 2019). Biomedical science students require the necessary skills to meet the demands of the 21st century. The Framework for 21st Century Learning identifies the 4Cs (critical thinking and problem solving, communication, collaboration, and creativity and innovation skills) that encompass the 21st century skills (Partnership for 21st Century Learning, 2007). Literature shows that the shift from didactic teaching to use of student-centred active learning approaches has improved students' learning experiences and academic performance thereby enhancing their 21st century skills (Freeman et al., 2014; Solomon et al., 2018; Whitworth, 2016). The meta-analysis conducted by Rahman and Lewis (2020) evaluated the effectiveness of evidence-based instructional practices, specifically in tertiary chemistry education, on students' academic performance. Ninety-nine studies were evaluated, and the instructional practices investigated were cooperative learning, collaborative learning, problem-based learning, process-oriented guided inquiry learning, peer-led team learning, and flipped classroom. The results revealed positive impact on students' academic performance, although, the effectiveness was lower for cumulative assessment when compared with single-topic assessment. Assessment topic coverage and setting size were identified as confounding variables that hindered a comparison of the relative effectiveness of the instructional practices. Similarly, Freeman et al. (2014) meta-analysed 225 studies to investigate the effectiveness of active learning in tertiary science, technology, engineering, and mathematics (STEM) courses. Their results indicated that the average examination scores improved by 6% when active learning was used in comparison to traditional lecturing. Active learning activities identified in the studies included group activities, in-class worksheets, clickers, problem-based learning, and studio classrooms.

The impact of active learning strategies has also been investigated in nursing education. Breytenbach, Ten Ham-Baloyi and Jordan (2017) conducted a literature review of 16 studies and identified eight teaching strategies used by nurse educators: e-learning, concept mapping, Internet-based learning, web-based learning, problem-based learning, case studies, and evidence-based learning. Interestingly, gaming, as a teaching method, was found to be less preferable when compared to formal, traditional teaching. Problem-based learning, although more enjoyable, did not reveal any increase in knowledge outcomes when compared to lecture-based formal teaching strategy. A similar finding was noted about learning through case studies. Concept mapping, internet-based learning, and evidence-based interactive strategies resulted in positive impact on knowledge outcomes. The authors suggest the use of multiple teaching strategies in nursing classrooms to meet students' needs and different learning styles. Other studies investigated simulation and flipped classrooms in nursing education (Jumah & Ruland, 2015; Njie-Carr et al., 2017) respectively. The findings of the review by Jumah and Ruland (2015) indicated that simulation had significant positive outcomes when compared to traditional lecturing in skill performance, competence, and student satisfaction. Similarly, Njie-Carr (2017), in their review of flipped classroom models in nursing education, found positive outcomes from collaborative learning, active learning, critical thinking and decision-making skills for effective patient management, however, with a recommendation of more rigorous studies using adequate sample sizes and sound research design.

It is evident from this literature that many biomedical science academics are redesigning their curriculum and incorporating instructional practices to provide active learning opportunities for students. Despite the growing awareness of EBTPs, there seems to be some resistance towards implementing EBTPs by instructors (Bathgate et al., 2019), and so it is important to convey the benefits of EBTPs to the wider academic community. It is essential to inform the biomedical science instructors that there is a body of evidence that supports active learning in biomedical science. Systematic reviews are generally considered to provide the best evidence for all research questions (Gopalakrishnan & Ganeshkumar, 2013). This systematic literature review investigates the literature on EBTPs implemented in those disciplines with biomedical science as their foundation, and further explores the effectiveness of teaching practices on students' learning experiences. The working definition of 'biomedical sciences' as applicable to this study includes: all fields of biology, molecular sciences, and medicine that focus on human health. The aim of this review is to investigate the best available literature on EBTPs that can be used by biomedical science instructors. The research questions framing this study are:

1. What are the EBTPs being used in biomedical science education?
2. What is the impact of EBTPs on students' learning experience?

Method

The protocol for this systematic review was developed using preferred reporting items for systematic review and meta-analyses (PRISMA-P) (Shamseer et al., 2015). This framework allowed for transparency, accuracy, completeness, and documentation of this systematic review.

Search Strategies

Studies were identified using ERIC, CINAHL PLUS, A+ Education databases and Google Scholar. The following keywords were used in conducting the search: *evidence-based teaching practice* (EBTP), *research-based instructional practice (RBIP)*, and *active learning*. EBTP and RBIP terminologies are interchangeably used in literature, hence both these terminologies were used in the search process. The disciplines included in the search were: medicine, nursing, pharmacy, biomedical science, genomics, molecular biology, virology, microbiology, immunology, biochemistry, anatomy, physiology, radiation, pharmacology, laboratory medicine, and medical radiation science. So as to yield valid and recent results, the search was restricted to peer-reviewed journal articles ranging from 2015 to 2021.

Inclusion Criteria

The inclusion criteria were established at the beginning of the work and included studies that: (i) investigated the effects of EBTPs, (ii) can be implemented in face-to-face classrooms, or online or blended modes, as well as theory, or laboratory or practical sessions, (iii) involved a course in medicine, nursing, pharmacy, biomedical science, genomics, molecular biology, virology, microbiology, immunology, biochemistry, anatomy, physiology, radiation, pharmacology, laboratory medicine or medical radiation science, (iv) involved empirical studies only, and (v) included data on outcome measures on some aspect of student academic performance or student learning experiences.

Data Analysis

The review synthesised empirical data that were obtained from different research designs. The process followed the guidelines indicated by Creswell (2018) that include: organising data for analysis, examining all of the data to reflect on the overall meaning, coding all of the data, and generating themes. The themes were categories of EBTPs that studies commonly implemented.

Critical Appraisal

The rigour of the studies was established using the Mixed Methods Appraisal Tool (MMAT) (Hong, Gonzalez-Reyes, & Pluye, 2018) as it supports critical appraisal for all types of study designs. As this review would include heterogeneous study designs, MMAT was considered appropriate for this systematic review. Risk of bias was assessed for individual studies by screening information on research questions, methodology, recruitment of participants, sampling strategy, integration of qualitative and quantitative data, and outcome data as relevant to individual studies. Each criterion was assigned a response of either ‘yes’, ‘no’, or ‘inconclusive’. A study was considered to be at *moderate risk* if it received two or more ‘no’ responses, while a study was considered to be at *low risk* if it received two or more ‘yes’ responses.

Results

Search Strategy

The search yielded 546 studies, and 13 duplicates were removed. The titles and abstracts for 533 articles were screened for potential eligibility of implementing EBTPs. They were sourced from various types of publications such as books, abstracts, conference papers, editorials, as well as, dissertations. Studies written in languages other than English were excluded. Based on the described methodology and eligibility criteria, the review identified 78 relevant papers. Three studies were qualitative, 65 studies were quantitative, and 10 studies used mixed-methods designs. Figure 1 provides a flow chart of the search strategy along with the outcomes. Critical appraisal of the 78 studies included in this systematic review indicated *low level* of bias for 73 studies and *moderate level* of bias for five studies.

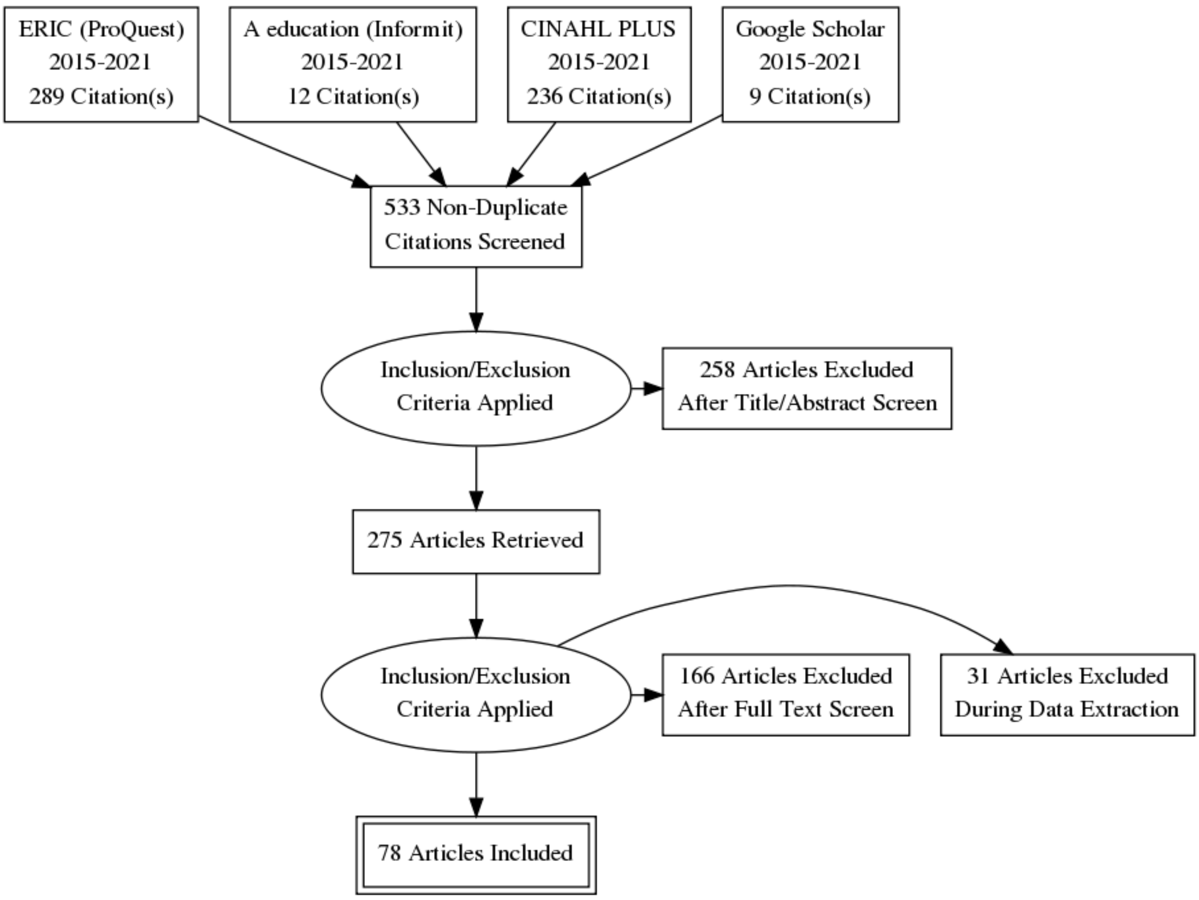

Figure 1. PRISMA flowchart for the systematic review detailing the databases searched, the number of duplicates screened, the number of abstracts screened, and the full texts retrieved. 78 articles retrieved.

Study Characteristics

Of the 78 studies, three were conducted in biochemistry courses, three in anatomy and physiology courses, and one in a pathobiology course. Other courses involved students enrolled in various undergraduate degree programs such as dentistry, medicine, pharmacy, nursing, chiropractic, paramedic bioscience, and molecular biology.

Outcomes

The EBTPs ranged from process oriented guided inquiry learning (POGIL), clicker responses, flipped classroom, student-centred learning with group discussions, educational gaming, inquiry-based learning, case-based learning, Interteaching, use of formative assessments, debates, and various active learning exercises. These active learning strategies involved students participating in group discussions, oral research presentations, think-pair quizzes, blog construction, image-based exercises, as well as drawing anatomical components. Many EBTPs were complemented with technologies such as FlowJo cytometry analysis software for detecting fluorescent-labelled molecules, mobile augmented reality technology, ultrasound, spirometry devices, and computer-based simulators, while others were supported with educational tools such as analogical models and visual field defects masks. Outcome measures for studies included pass and fail rates, student grades, student satisfaction, educational activity outcomes, exam performance, attitudes towards the practices, student perceptions, and scores on critical thinking skills.

Discussion

This systematic review sought to answer two research questions: (1) What are the EBTPs being used in biomedical science education? and (2) What is the impact of EBTPs on students' learning experience?

Evidence-Based Teaching Practices in Biomedical Science

There is an implication on educators that they implement pedagogies that enhance skills in students to meet the demands of the 21st century (Kivunja, 2014). Accordingly, 21st century pedagogies identified in the literature include, but are not limited to, inquiry-based learning, problem-based learning, collaborative learning, experiential learning, constructivist learning, personalised learning, and flipped-classroom learning. These pedagogies utilise the social constructivism view of learning, whereby, students construct knowledge by interacting with other learners (Vygotsky & Kozulin, 1986). The instructional strategies identified in this review align with the 21st century pedagogies discussed in the literature. These are: problem-based learning, team-based learning or collaborative learning, flipped classroom, simulation, POGIL, case-based learning, project-based learning, formative evaluation, and inclusive pedagogies. Educators conceptualised and operationalised the instructional strategies differently based on the nature of the course taught, year level, and size of the class.

Flipped classroom intervention included pre-class and in-class active learning activities that ranged from use of jigsaw activity to use of clickers, debates, group projects, case studies, guest speakers that allowed peer interactions and team-based learning. Most of the pre-class learning materials ranged from PowerPoint slides, videos and reading resources. Two studies adopted semi-flipped model slightly different to that of others whereby only a few lectures in the whole term were flipped with the remainder of the sessions presented in the traditional didactic style (Chan, Tang, Chow, & Wong, 2021; Gorres-Martens, Segovia, & Pfefer, 2016). Workload and technical issues were some of the barriers identified in the studies towards implementation of the flipped model. This implies that the flipped model needs a design that has an appropriate blend of pre and in-class activities.

Simulation as an instructional strategy was used mainly in nursing and medicine cohorts where students required to learn physiology and pathophysiology concepts within a clinical context. Jumah and Ruland (2015) describe simulation as a pedagogical approach that replicates real life situations to allow learners to practice decision making and perfect psychomotor skills in a safe environment. Based on this description, studies in the current review that implemented simulation were analysed. The findings of this review were similar to those identified in the literature in terms of student satisfaction, skill performance, knowledge acquisition, and self-confidence.

A comparative analysis of case-based learning, collaborative learning and problem-based learning revealed overlapping components amongst these instructional strategies. Collaborative learning was established by getting students to work in groups to solve case studies, problem-solving, debates, teaching to peers, paper presentations, and designing exam questions. Similarly, case-based learning presents an umbrella term that encompasses a range of instructional strategies, including inquiry-based learning, problem-based learning, and project-based learning (Derfoufi et al., 2015) where students work on case studies. The assessment coverage varied across the studies with most studies employing single-topic assessments or assessments on modules that employed the intervention. Very few studies used cumulative assessments to evaluate the effectiveness of the intervention (Cleveland, Olimpo, & DeChenne-Peters, 2017; Huitt, Killins, & Brooks, 2015). Variation in setting size was also identified across the studies that implemented these instructional strategies and should be considered as a confounding variable while comparing the effectiveness of the instructional strategies.

Six studies used an inquiry learning process as an instructional method, two closely associated with POGIL that allows students to practise process skills (problem solving, deductive reasoning, communication, and self-assessment) while engaged in a guided inquiry (Bentley, Robinson, & Ruscitti, 2015; Brown, 2016; Eberlein et al., 2008; King, Van der Touw, Spowart, & Lawlor, 2016; Nybo & May, 2015; Sinnayah, Rathner, Loton, Klein, & Hartley, 2019). This approach allowed students to apply their content-based knowledge to process-specific knowledge using scientific process. Positive outcomes were identified in all the studies that employed inquiry-learning process. Inclusive strategies involved hands-on activities to cater to auditory, visual, and kinaesthetic learners. This involved use of board games, puzzle, physical models, props, and drawing.

Impact Of Evidence-Based Teaching Practices on Students' Learning Experience

The outcome measures were thematically categorised into four major themes: students' performance, students' attitudes, higher-order thinking skills, and self-directed learning. Each of these themes are discussed in the following sections.

Students' Performance

The EBTPs implemented in the studies had significant effects on students' performance, which was determined by evaluating either pass and fail rates or grades for the enrolled units. Post-intervention, statistically significant results were noted in the mean test scores denoting significant improvement in performance. One study, that implemented a pre-lecture screencast with a multiple-choice question (MCQ) quiz, showed improvement in average grades for MCQ quizzes from the first attempt to last attempt (Kinsella, Mahon, & Lillis, 2017). However, there was no noticeable impact on academic achievement when compared to the previous year. Possible reasons suggested by the authors are the learners' varied levels of prior knowledge, and pre-lecture screencasts not being a part of continual assessment. These factors may have deterred students from engaging with the screencast resources. Two studies revealed a significant increase in knowledge retention (Kulak & Newton, 2015; Raupach et al., 2016). Of equal importance was the difference in the academic achievement noted in strongly-performing and poorly-performing students that was found in a study conducted by Carrasco, Behling, and Lopez (2019). The strongly-performing students benefitted from group work, while poorly-performing students benefitted from individual work when preparing for Readiness Assurance Test exercises (Carrasco et al., 2019).

Similarly, Green, Cates, White, and Farchione (2016) investigated the effect of collaborative practical tests on students' understanding of gross anatomy. The findings revealed that there was no correlation between collaborative practical tests and the final exam mark, suggesting that collaborative practical testing is not effective in improving individual student exam marks. A negative outcome was also revealed in a study by Grosas, Raju, Schuett, Chuck, and Millar (2016) that implemented formative assessment process as an EBTP. Formative assessments caused minimal improvement in the final exam performance and the researchers concluded that the ineffective feedback provided in the assessments did not empower students to improve their achievement. Additionally, another study by Carlson, Chandra, Hobbs, and Steele (2019) that used clay modelling as an active learning strategy did not reveal any significant improvement in exam performance, while indicating that time restrictions, group dynamics, and task instructions could be factors hindering the desired outcome.

Positive Attitudes

The purpose of implementing EBTPs is to maximise learning experiences for students. This can be achieved by creating engaging learning materials, creating opportunities for students to engage with peers and instructors, constructively aligning assessment tasks to the desired learning outcomes, providing opportunities for critical thinking, and, most importantly, making explicit the connections between the content and future professions. To that end, the EBTPs explored in this review created positive environments that were conducive to student learning. Students' perceptions gathered through survey responses revealed positive attitudes towards various aspects of learning components: teamwork (Brown, 2016; Huitt et al., 2015; Tarhan & Ayyildiz, 2015); usefulness of resources in learning (Fyfe, Fyfe, Dye, & Radley-Crabb, 2018); learning experiences (Abraham, Vashe, & Torke, 2015; Chen, Kelly, Hayes, Van Reyk, & Herok, 2016; Derfoufi et al., 2015; Gorres-Martens et al., 2016; Kulak & Newton, 2015; Matsuda, Azaiza, & Salani, 2017; Muthukrishnan et al., 2019; Youngwanichsetha, Kritcharoen, Chunuan, Kala, & Phumdoung, 2020); interest in biochemistry (Tarhan & Ayyildiz, 2015); accessibility to the instructor (Gonzalez & Gadbury-Amyot, 2016), cognitive load (Gross, Wright, & Anderson, 2017); engagement in scientific inquiry (Brown, 2016); experiment instructions (King et al., 2016); relevance of the teaching practices (King et al., 2016); exam experience (Ahlstrom & Holmberg, 2021); empathy towards older persons (Lucchetti, Duarte, Assis, Laurindo, Lucchetti, 2019); enjoyment (Kukolja Taradi & Taradi, 2016), and use of technology (Hardie et al., 2020).

Higher-Order Thinking Skills

Educators have highlighted that within biomedical science disciplines students are required to develop scientific inquiry, experimental, research-based, and critical thinking skills (Breytenbach et al., 2017; Colthorpe et al., 2015; Njie-Carr et al., 2017). Skills, such as critical analysis, problem-solving, collaboration, and team-work, allow health workers to work interdependently and to make sound scientific and clinical decisions based on evidence (Brown, Alshiraihi, Hassell, & Lanning, 2020). To that end, this review identified EBTPs that promote such higher-order thinking skills. Teaching practices such as case-based learning, group discussions, flipped classroom approaches, and gaming have improved problem-solving, critical thinking skills, and communication skills (Chan et al., 2021; Cicuto & Torres, 2016;

Derfoufi et al., 2015; Mahaffey, 2019; Marcondes et al., 2015; Montrezor, 2016; Muthukrishnan et al., 2019; Youngwanichsetha et al., 2020). In the study by Lucchetti et al. (2019), that used a combination of different active learning methods including simulated scenarios, real-patient encounters, gaming, and jigsaw puzzles, improvements in clinical skills for geriatric medicine were identified. These skills were assessed using the validated tool, the Clinical Skills Assessment questionnaire. Similarly, Styers, Van Zandt, and Hayden (2018) investigated the effect of a flipped classroom approach using the Critical Thinking Assessment Test on students' critical thinking skills. The results indicate higher post-test Critical Thinking Assessment Test scores especially from under-represented minority students (Styers et al., 2018). Active learning strategies, such as use of debate, dialogical narrative approach, and guided-inquiry based instruction, promoted critical thinking and stimulated higher-order thinking skills as students were involved in thinking, questioning, processing, and then presentation of scientific data (Ghiam, Loftus, & Kamel-ElSayed, 2019; Hardie et al., 2020; Kedraka & Kourkoutas, 2018; Mumtaz & Latif, 2017; Nybo & May, 2015). The outcome measures for these studies were gathered by evaluating students' opinions through focus group interviews. Similarly, EBTP such as deep reading of papers implemented in a study by Peng (2017) enhanced research skills as students got involved in literature search, analysing, evaluating, and presenting of research data.

Self-Directed Learning

Self-directed learning is defined as an ability to control, manage, and plan learning actions, and encompasses cognitive strategies such as rehearsal, metacognitive strategies such as monitoring and planning, and resource management strategies such as seeking peer support (Broadbent & Poon, 2015). These active learning strategies allow students to achieve positive academic outcomes and the clinical skills required in biomedical science disciplines. Findings from a study that implemented Interteaching, a behavioural approach to learning, whereby instructors prepared study guides, revealed that students undertook responsibility for their own learning and showed improvement in their study habits (Estridge & Owens, 2018). Another study that implemented a flipped classroom model identified enhanced metacognitive awareness as an outcome (Chan et al., 2021). Similarly, McLean, Attardi, Faden, and Goldszmidt (2016) in their study on flipped classroom and learning behaviours identified that students developed independent learning strategies such as note-taking, reviewing, and metacognitive awareness such as time management, understanding and reflection, as well as highly-valued opportunities for peer interactions. Further, the findings revealed that students spent less time on multi-tasking behaviours and preferred a 'just-in-time' teaching approach. Data from questionnaires and focus group interviews revealed that teaching practices complemented with technology supported students in their self-directed learning as students improved in their organising, retrieving, collaborating, and presenting skills (Abraham et al., 2018; Garrett, Jackson, & Wilson, 2015).

Conclusion

This study sought to provide a biomedical science discipline-specific synthesis of EBTPs through a systematic review. To that end, the identified literature comprised of robust research studies that included qualitative, quantitative descriptive, experimental, quasi-experimental, and mixed-methods research studies to date. The results revealed that cohorts using EBTPs have positive impact on academic performance and student learning experience. The findings of this study contribute to the body of literature to reveal that EBTPs in biomedical science promote active learning and are based on sound evidence. Clearly, the teaching approaches identified in this review allowed for cognitive activation in students, classroom management, and student learning support thereby meeting critical dimensions of teachers' instructional practice. It is not within the scope of this review to suggest superiority of one instructional strategy over the other. However, instructors are encouraged to refer to these EBTPs and consider what is the best suitable in a given educational setting.

Implications for Practice

This systematic review was intended to inform instructors within the biomedical science disciplines about the advantages of using EBTPs. It is highly recommended that multiple active learning strategies are implemented alongside the lecture materials so that they serve as complementary strategies. Successful implementation of EBTPs will require institutions to provide instructors with necessary resources in regards to professional learning as well as funding resources wherever applicable. This has implications for higher education institutions, educators, policy makers, administrators, and health practitioners involved in curriculum and pedagogical decisions related to the implementation of EBTPs.

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