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Polymer Science in Action: Transforming the Learning Experience for Undergraduates with Active Learning Strategies

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Abstract. Active learning is a powerful teaching and learning approach that enhances students' capacity to construct understanding and apply their knowledge in real-world contexts. However, in university science classes, lectures remain the predominant method employed by instructors, primarily due to time constraints and limited familiarity with active learning strategies. This study aimed to explore practical guidelines for implementing active learning in undergraduate polymer science classrooms, as well as the perspectives of instructors and students on this approach and student satisfaction with active learning. The research involved two instructors and 34 second-year students from the Faculty of Science at a university based in Bangkok, Thailand. Data were collected through classroom observation, a student satisfaction questionnaire, and instructor and student interviews. Data were analyzed quantitatively, using means and standard deviations, as well as qualitatively, using content analysis. The study identified four practical guidelines for implementing active learning in the undergraduate polymer science classroom, which are: using a variety of active learning strategies and techniques that match the nature of students; providing helpful learning media and technology; using higher-level questioning to promote thinking processes; and linking authentic assessment and constructive feedback with real-life situations. These four guidelines proved effective for both on-site and online forms of learning. Furthermore, the students expressed very high satisfaction levels (M = 4.64, SD = 0.49) and positive opinions regarding active learning.

Keywords: active learning; undergraduate students; action research; practical guidelines

1. Introduction

Through its diverse range of academic programs and courses spanning various fields, higher education equips students with the specialized knowledge, skills,

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and experiences necessary for success in their chosen careers. Universities have a multifaceted role in shaping learners for work, life, and lifelong learning by transforming their perspectives and fostering conceptual change through the adoption of student-centered teaching approaches instead of mere knowledge transmission (Healy et al., 2020; Yates & Hirsh, 2022). Therefore, universities must emphasize effective teaching and learning methods to develop quality learners who possess both the knowledge and skills needed for work and life and who are committed to lifelong learning (Vereijken & Rijst, 2021). To achieve this goal, teaching and learning methods should cater to learners' needs and encourage their holistic development. However, a review of the literature on teaching and learning in higher education illustrates that lecturing remains the most commonly used method for delivering information to students (Bi et al., 2019; Stecula & Wolniak, 2022). Instructors have the responsibility of determining the content structure and selecting appropriate teaching approaches, based on their expertise. In terms of content structure, instructors are involved in designing or developing the curriculum for their courses, including selecting appropriate content, organizing it in a logical sequence, conducting appropriate assessment, and ensuring alignment with learning objectives and standards. Furthermore, instructors also have to select and employ appropriate teaching methods based on the subject matter, course goals, and the needs of their students (Odebiyi, 2022; Tatto, 2021). This highlights the need to explore and adopt innovative and effective teaching and learning methods to enhance student learning outcomes and prepare them for the demands of the 21st century.

The traditional lecture-based teaching method has long been the go-to approach at the university level, resulting in a passive learning experience for students (Bi et al., 2019; Kim et al., 2019). Unfortunately, this approach can lead to disengagement and disinterest among students, which may hinder their ability to fully develop their potential. Instructors may be hesitant to adopt new teaching strategies due to time constraints and lack of knowledge, and the classroom environment may not always support active learning (Kim et al., 2019). Al-Rawi (2013) has pointed out the limitations of the lecture method, which mainly focuses on content delivery through one-way communication. In particular, this approach is commonly used in science courses at the university level, further perpetuating the passive learning experience. Students often have limited opportunities to actively engage in discussions or ask questions. Lectures can sometimes overload students with a large amount of knowledge while providing limited opportunities for feedback (Kim et al., 2019). At the university level, science instructors are expected to possess strong knowledge of scientific content and provide students with practical laboratory experiences and materials (Cho & Baek, 2019; Waldrop, 2015). Commonly used methods for assessing students' knowledge include tests, quizzes, research projects, report writing, and presentations. However, despite their expertise in scientific content, many instructors lack knowledge of effective teaching strategies that promote active learning, resulting in fewer opportunities for students to engage actively in the learning process (Heck et al., 2023; Kim et al., 2019). This can have a direct negative impact on students' potential for learning and academic success.

Active learning is a powerful teaching and learning approach that promotes students' ability to construct their own understanding and apply knowledge in real-world settings (Cooper et al., 2018; Hao et al., 2021). Unlike passive learning, which relies on rote memorization, active learning encourages students to engage with the material and think critically about the concepts being taught, leading to higher levels of cognitive development (Waldrop, 2015). Compared to traditional teaching methods, active learning allows students to engage in classroom discussions and learn in a more interactive manner, leading to the development of long-term memory and better application of knowledge (Waldrop, 2015). Forms of active learning in the classroom can vary, depending on factors such as the nature of students, the problems being addressed, the learning activities, and the feedback provided by instructors (Schmidt et al., 2015). As a result, active learning has been shown to improve learning outcomes and promote a deeper, more accurate understanding of the material. Moreover, students find active learning activities to be enjoyable and engaging, as they have the opportunity to develop their higher-order thinking skills through hands-on experiences (Kim et al., 2019). Active learning is a versatile teaching approach that can be applied both inside and outside the classroom, benefiting students at all levels in individual, small-group, and large group settings (Sandrone et al., 2021; Silberman, 1996). Furthermore, it has been effectively employed to enhance undergraduate science education across a wide range of scientific concepts (Clark, 2023; Hao et al., 2021; Nardo et al., 2022; Perasso & Dominguez, 2023). However, despite the recognized benefits of active learning in improving students' scientific achievement and academic performance in various aspects, several limitations and barriers to its implementation in undergraduate science classrooms have been revealed.

When considering the teaching and learning of science at the undergraduate level, prior research has investigated the impact of active learning. Nardo et al. (2022) found that, in an introductory chemistry course, while active learning methods engaged students with varying preparation levels, some found worksheets unengaging and group work stressful due to peer concerns. Students recommended dedicating more time to group work for better engagement and collaboration. However, most undergraduate students have a positive attitude towards active learning and appreciate the way in which it helps them to engage more in class and improve their learning processes through various methods and approaches (Downing et al., 2020). It is crucial to focus on students when implementing active learning, and there are strategies to assist university instructors in changing their teaching style. Studies by Kim et al. (2019) and Heck et al. (2023) explored the barriers to incorporating active learning into science lecture classes and strategies for overcoming them. A key barrier was revealed to be a lack of time for developing learning materials and insufficient class time. Instructors need more flexible schedules and recognition for their teaching efforts. Furthermore, successful implementation hinges on educator support, with science instructors requiring training in effective teaching methods. Thus, collaborating with science educators to enable them to implement active learning in their courses can bridge this gap. Additionally, extracting practical guidelines for active learning in undergraduate science classrooms would greatly benefit the implementation of this research.

In 2019, the Covid-19 pandemic caused major lifestyle, economic, and societal changes worldwide, leading to a shift from on-site to online learning at all levels, including universities. Successfully adapting teaching and learning strategies to this new format requires a commitment to the principles of active learning. This research, conducted in collaboration between polymer science instructors and science educators in Bangkok, Thailand, aimed to provide guidelines for using active learning in an undergraduate polymer science classroom for students during the pandemic and beyond. It reports on the obstacles encountered by both teachers and students. The polymer science course is a two-credit, lecture-based class for second-year Materials Science undergraduates. Traditionally, teaching focused on concepts, and evaluations were mainly conducted through midterm and final examinations. However, this research was conducted during the transition from normalcy to the Covid-19 pandemic situation. The course was initially face-to-face, but the second half shifted to online learning, with active learning approaches being used in both settings.

2. Literature review

2.1 Active learning

Active learning is an instructional approach that has gained significant attention and recognition in the field of education over the past few decades. This pedagogical method emphasizes engaging students in the learning process through various activities and exercises that go beyond traditional passive learning techniques, such as lectures and readings (Kim et al., 2019). Specifically, active learning is designed to promote critical thinking, problem-solving skills, and deeper understanding of the subject matter by requiring students to actively participate in their own learning (Hao et al., 2021; Sekwena, 2023). Furthermore, active learning is a versatile teaching approach that is effective for learners of all levels, including individual, small group, and large class settings (Silberman, 1996).

One of the key principles of active learning is student involvement in meaningful and relevant activities. These activities can include group discussions, problem-solving exercises, hands-on experiments, case studies, peer teaching, and technology-enhanced learning tools (Silberman, 1996; Strubbe et al., 2019). Active learning environments are designed to foster collaboration, communication, and interaction among students, creating a dynamic and engaging classroom atmosphere (Hodges, 2020) and helping students to identify areas for improvement through prompt feedback (Hodges, 2020; Strubbe et al., 2019). Research overwhelmingly affirms the advantages of active learning. Students in active learning environments consistently outperform their counterparts in traditional lecture-based classes, resulting in improved academic performance and a deeper grasp of the subject matter (Strubbe et al., 2019).

Moreover, previous studies have revealed that active learning can enhance and promote students' long-term retention (Minick et al., 2022), promoting learning motivation (Owens et al., 2020) and the ability to apply knowledge to real-word situations (Hodges, 2020; Silberman, 1996). In addition, active learning can be applied to students through diverse learning styles (Sandrone et al., 2021; Silberman, 1996). It empowers students to become active participants in their own learning journeys, preparing them for the challenges of an ever-evolving world.

2.2 Active learning strategies and media

Numerous active learning strategies are employed in diverse classroom settings. One of the main active learning strategies commonly used in classrooms is group discussion, in which students collaborate in small groups to exchange their ideas, encouraging peer interaction and the development of communication skills (Sandrone et al., 2021; Silberman, 1996; Strubbe et al., 2019). Another key strategy is think-pair-share, which involves posing a question or prompt to students, allowing them time to think individually, then pairing them up to discuss their thoughts before sharing them with the whole class (Cooper et al., 2021). The jigsaw method is also employed, whereby students work in groups to become experts on specific topics and then share their knowledge with their peers (Baken et al., 2022). Role-playing is another active learning approach, in which students take on specific roles or characters related to the concepts (Effendi, 2021). Interactive technology can enhance active learning as well; online quizzes, interactive simulations, discussion boards, and virtual labs provide opportunities for students to actively engage with course material (Cole et al., 2021).

Combined with diverse media resources, active learning strategies create a dynamic and engaging educational environment. Active learning strategies often involve interactive elements such as discussions, debates, group projects, and problem-solving activities. These strategies are greatly enhanced through the use of multimedia presentations, virtual simulations, and online discussion platforms. Interactive media tools allow students to collaborate, explore, and apply their knowledge in a dynamic and engaging manner (Jesionkowska et al., 2020). This helps students better understand complex concepts through various sensory channels.

2.3 Active learning in the undergraduate science classroom

Active learning has been employed to enhance students' attainment at all levels of education. In particular, in undergraduate science classrooms, active learning can be applied across various scientific concepts. Previous research has examined various teaching methods related to active learning in undergraduate science classrooms, in both online and on-site learning settings. These methods include group work activities with worksheets, videos, and textbook reading tasks with targeted questions (Clark, 2023; Hao et al., 2021; Nardo et al., 2022; Perasso & Dominguez, 2023), the flipped-classroom approach, and discussions (Clark, 2023). Additionally, Interactive Lecture Demonstrations involving experiments have been explored (Perasso & Dominguez, 2023).

Several recent studies have explored the effectiveness and challenges of implementing active learning in diverse educational contexts. Nardo et al. (2022) conducted research in an introductory chemistry course and found that, while active learning methods such as worksheets and group work were utilized, they posed significant equity challenges. Students with varying levels of prior preparation found worksheets unengaging and group work stressful due to concerns about fitting in with their peers. Moreover, students suggested that more time should be dedicated to group work to improve engagement and collaboration. Hao et al. (2021) focused on the impact of active learning environments in computer science education and noted that active teaching methods positively affected outcomes, irrespective of variations in the learning environment.

In another study, Perasso and Dominguez (2023) examined the influence of an adapted Interactive Lecture Demonstration (ILD) in an Acoustic Physics course for first-year university students. The results indicated that students responded positively to this modified ILD, which encouraged them to take a more active role in their learning. Furthermore, Clark (2023) investigated student performance in general chemistry classes, comparing active in-person learning with traditional methods used during emergency remote teaching. The study found that underrepresented minority students in the active learning classes, regardless of the teaching environment, had significantly smaller achievement gaps than those in traditionally taught classes. This highlights the importance of effective course structure and teaching approaches, extending beyond in-class active learning, in promoting student success.

Implementing opportunities for active learning in undergraduate science classrooms presents a challenge for college and university lecturers. According to the study by Kim et al. (2019), which unveiled the obstacles to adopting active learning in lecture classrooms based on the opinions of academic staff in biomedical science, the primary reason educators persist with traditional lecture-based teaching methods is the class sizes. Most of the respondents reported that they aspire to change their teaching styles to incorporate active learning, aiming to enhance student engagement and foster active participation among students. However, the principal barrier they face in making this transition is a lack of time. Another significant hurdle is the lack of recognition for their teaching efforts. Lecturers often prioritize research grants and publications, considering them key indicators for career advancement. A study conducted by Heck et al. (2023) yielded similar findings, highlighting personal barriers such as a shortage of time for developing learning materials and inadequate class time. More notably, a dearth of training in active learning strategies was identified as another significant obstacle faced by science university lecturers.

3. Objectives

The research aims to 1) establish practical guidelines for active learning in a polymer science classroom; 2) study instructors' and students' views; and 3) explore student satisfaction with learning.

4. Methods

4.1 Research design

The research design of this study was classroom action research, which followed the PAOR cycle (Kemmis & McTaggart, 1988), including eight cycles. Each cycle consisted of four continuous steps, which are described as follows.

Plan: This step involved exploring problems in developing teaching and learning in the polymer science classroom, with an emphasis on active learning for undergraduate students. The researchers trained the instructors in the features of active learning, explained how to apply active learning in the science classroom, and provided examples of active learning classes, strategies, and techniques. Instructors and researchers worked together to plan, discuss problems, design learning activities, and choose appropriate teaching strategies and techniques for each lesson plan.

Action: Next, the developed lesson plans were implemented in the classroom. Instructors taught their students based on the lesson plans they had created in the initial step.

Observe: This step ran parallel to the action step. The researcher acted as a classroom observer, monitoring the instructors' teaching behavior, as well as undergraduate students' learning behavior, using a classroom observation form.

Reflect: In this step, instructors reflected on what had happened in the class. Instructor interviews were used to collect information based on their opinions and perceptions. Then, the researcher and instructor discussed these reflections to identify ways of improving the next lesson.

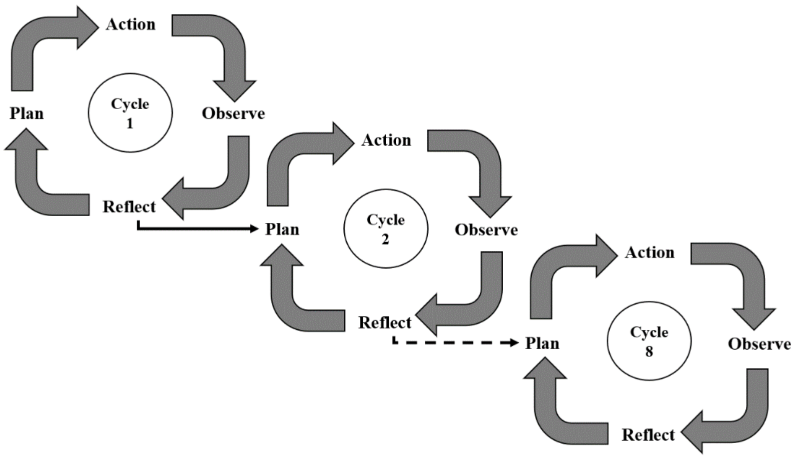

Figure 1: The PAOR cycle (Kemmis & McTaggart, 1988)

4.2 Participants

The study involved 34 sophomore students and two instructors from the Faculty of Science at a university located in Bangkok, Thailand. The instructors were motivated to enhance their teaching skills by incorporating active learning strategies. Instructors were included if they met the following criteria: 1) Teaching polymer science courses; and 2) Willingness to voluntarily adopt the active learning approach in their polymer science class. Student participants were required to meet the following inclusion criteria: 1) Enrollment in the course during the first semester of the 2020 academic year; and 2) Consent to participate in the data collection process for this research.

4.3 Instruments
The instruments used in this research were developed based on Behaviorist and Constructivist theories. The Behaviorist theory emphasizes and identifies the observable behaviors exhibited by teachers and students in relation to active learning. The Constructivist theory plays a central role in understanding the ways in which students engage in learning and in capturing evidence of students constructing their own understanding. To achieve the objectives of this research, the following research instruments were utilized.

1) Classroom observation form. To record the instructors' teaching competency and behavior, as well as undergraduate students' learning behavior in the active learning polymer science classroom, the researchers utilized a classroom observation form. The form consisted of descriptive texts in four aspects: i) implementation of various and appropriate active learning strategies and techniques; ii) use of media and technology for teaching and learning; iii) construction and organization of learning activities that emphasize the promotion of higher-order thinking; and iv) assessment of students in compliance with the course learning outcomes based on authentic assessment.

2) Instructor interview protocol. The semi-structured interview protocol was used to gather data from the instructors after each weekly lesson. The following questions were included:

1. How did you organize the learning in this class? Please identify the active learning strategies that you used.
2. How do you provide feedback to students?
3. How do students respond to the learning activities?
4. What challenges or obstacles did you encounter during the class?

3) Student interview protocol. The semi-structured student interview protocol was employed to gather data from students after the completion of the first and second halves of the semester. The protocol consisted of the following questions:

1. What do you think about learning in the polymer science course in terms of instructors, learning activities, and assessment methods in the first/second half of the semester?
2. Which learning activity did you enjoy the most? Please elaborate.
3. How did the instructors provide feedback to you during the course?
4. What difficulties or obstacles did you encounter during the first/second half of the semester, and what suggestions would you like to make to improve the course?

4) Student satisfaction questionnaire. The student satisfaction questionnaire was developed by the researchers and consisted of 26 items rated on a five-point scale, focusing on three aspects: 1) teaching and learning process (14 items); 2) learning media (four items); and 3) measurement and evaluation (eight items). The interpretation criteria for satisfaction levels are based on the mean and divided into five categories: very high (4.51-5.00), high (3.51-4.50), moderate (2.51-3.50), low (1.51-2.50), and very low (1.00-1.50).

All the research instruments were evaluated by three experts in the field of science education to ensure their validity. The Index of Consistency (IOC) was found to be within an acceptable range of 0.67-1.00.

4.4 Data collection

Before the start of the first semester of the 2020 academic year, the researcher and instructors collaborated to discuss the features and characteristics of active learning. In the role of a science educator, the researcher provided relevant information on how to incorporate active learning in the science classroom. This included offering the instructors examples of active learning classes and sharing teaching strategies and techniques, along with guidelines for constructing effective learning activities. The instructors then planned and created learning activities, selecting appropriate teaching strategies and techniques for the polymer science course, a lecture-based course with two credits for second-year undergraduate students majoring in Materials Science. This planning was based on consultations with the science educator. Starting from the first loop of action research, the instructors designed the initial lesson plans for week one, choosing active learning strategies alongside technology and media integration. They subsequently implemented these lesson plans, observed student behaviors, and provided feedback. Along with the researcher, the instructors then reflected upon the results of the first lesson plan, leading to the planning of the second lesson plan, and this iterative process continued for eight cycles. The two instructors conducted the course over 16 weeks, including midterm and final examinations, with two-hour sessions each week. For further details on the course content, please refer to Table 1.

Table 1: Content of the polymer science course

Week	Topics	PAOR cycle
1	Introduction to polymer science	1st cycle
2	Polymer synthesis and chemical structure	2nd cycle
3	The molecular mass of polymers	3rd cycle
4	Morphology and crystal structure of polymers	4th cycle
5	First quiz	
6	Crystallization and melting	5th cycle
7	Vitrification	6th cycle
8	Midterm examination	
9-10	Polymer properties and characterization	7th cycle
11	Second quiz	
12	Application of polymers	8th cycle
13-15	Group work and presentation (independent study related to polymers)	
16	Final examination	

Throughout the course, the researcher closely observed each class using the classroom observation form. In addition, after every session, the instructor was interviewed to reflect on the progress and discuss areas for improvement. These insightful discussions served as a valuable tool for fine-tuning the course and creating an environment that was more conducive to learning. Furthermore, the feedback gathered from the students was also crucial in evaluating the effectiveness of the course. At the end of the semester, students were invited to complete a student satisfaction questionnaire, which included questions on the teaching and learning process, learning media, and measurement and evaluation. Some students volunteered to share their experiences and insights on the course through a student interview protocol, with 10 students being interviewed after the midterm examination and a further 10 students being interviewed after the final examination. This feedback was invaluable in shaping the course and ensuring that it was tailored to meet the needs and expectations of the students.

4.5 Data analysis

The data collected from the study while conducting action research were analyzed using both qualitative and quantitative methods. The qualitative data analysis involved evaluating the instructors' teaching competency, identifying the students' learning behaviors, and eliciting their opinions regarding teaching and learning through active learning techniques. The content analysis method was employed to identify practical guidelines for the implementation of active learning in the undergraduate polymer science classroom. To ensure the reliability of the research results, the researcher organized the data, identified the data coding, generated temporary conclusions, and summarized the guidelines. The summarized data were then verified by three other researchers to confirm the reproducibility, stability, and accuracy of the results (Krippendorff, 1980). The students' satisfaction towards their learning experience was analyzed quantitatively using mean and standard deviation. The mean scores were then interpreted to determine the overall level of satisfaction as well as satisfaction levels for each item. This comprehensive analysis allowed for a thorough understanding of the effectiveness of active learning in the polymer science classroom and provided valuable insights for future implementation.

5. Results

The research findings were divided into three parts as follows.

Part 1: Practical guidelines for using active learning in the undergraduate polymer science classroom

To address the first aim of this study, the focus was placed on identifying practical guidelines for implementing active learning in undergraduate polymer science classrooms. The data from weekly classroom observations (based on lesson planning and action research procedures), student feedback, and insightful instructor interviews were analyzed and synthesized into four practical guidelines, which are described as follows.

1) Use a variety of active learning strategies and techniques that match the nature of students.

This guideline was identified during the second cycle of action research. In the first cycle, the instructor planned the lesson, comprising an introduction, a teaching step, and a summary step. During the teaching step, the instructor delivered lectures and utilized questioning techniques to engage students and encourage their participation. However, upon reflection, the instructor observed that students were still not responding to the questions. This hindered the instructor from assessing students' comprehension and resulted in a lack of classroom participation during teaching. In the second cycle, the teacher enhanced students' participation in learning by introducing such techniques as think-pair-share. Instead of being completed individually, activities were now carried out in pairs, accompanied by questioning to encourage students to answer questions collectively. It was observed that students generally preferred not to work alone; instead, each pair made more effort to provide answers. This approach increased student engagement in learning, but there was still room for improvement in terms of summarizing knowledge. Therefore, in the third cycle, the instructor reorganized the learning process according to the aforementioned guideline. By introducing the use of mind mapping to summarize knowledge, the instructor not only enhanced student participation in learning but also facilitated a more accurate assessment of students' understanding.

Through classroom observations and interviews, it was evident that both instructors had used a range of techniques to promote student engagement and participation. During the first half of the semester, the first instructor employed think-pair-share, group work activities, questioning, and role-playing techniques to enhance learning outcomes. Meanwhile, the second instructor had to transition to online active learning due to the impact of the Covid-19 pandemic in Thailand during the second half of the semester. To facilitate student learning, the instructor used techniques such as mind mapping, group work, and jigsaw techniques. For more comprehensive information on the examples of active learning techniques used in the undergraduate polymer science classroom, please refer to Table 2 below.

Table 2: Examples of active learning techniques used in the polymer science classroom

Instructor	Active learning techniques	Explanations
1	Think-pair-share	Week 2: To gauge prior knowledge, the instructor used Kahoot to administer a 5-question multiple-choice pre-test at the beginning of class. During lectures, she engaged students with questions to facilitate discussions on polymer concepts. At the end of each class, students worked in pairs on a worksheet to consolidate their learning. To encourage participation, students volunteered to present their answers to the class.
1	Questioning and role-playing	Week 3: Students were asked to summarize the two main types of polymerization and make comparisons between them. The instructor prompted students to think before answering questions related to the concepts they had learned the previous week. Some questions required students to apply their knowledge to explain concepts such as the speed of polymerization. One such question was, "Which types of polymerization result in a greater molecular weight,

		and how do you know?" This type of question encouraged students to elaborate on their knowledge. In an attempt to help students better understand polymerization, the instructor provided a simulation activity in which the students acted as monomers trying to bond with each other. However, the instructor felt that the activity was not entirely suitable for the class since the two types of polymerization were different. Nonetheless, the activity helped students to grasp the basic idea of polymerization.
1	Group work	Week 4: In groups of 4-5, students worked on a worksheet that focused on repeating units of different polymers. The instructor encouraged students to think of their own questions and verify their answers with their group members. The instructor also posed questions such as, "Can you explain which type of polymerization this repeating unit comes from?" After the group work activity, the instructor explained the concept of polydispersity and asked students to confirm their understanding.
2	Mind mapping	Week 10: The instructor frequently asked questions about key terms and used graphs to aid in explaining processes. To reinforce understanding, the instructor repeated explanations a number of times and assigned students to create mind maps summarizing the concepts.
2	Group work	Week 11: The instructor asked students to work in pairs or small groups to research assigned polymers across 4-5 topics and provide task-specific examples. To facilitate collaboration, the instructor provided shared folders and Google documents for students to share their information.
2	Jigsaw	Week 12: The instructor began by asking students about polymer additives and presented a picture of an airplane to prompt their thinking about potential uses. The instructor then used the jigsaw technique to divide students into 5 groups of 7, to learn about 7 different polymer additives. Once all additives had been learned, students regrouped to summarize their findings on paper.

2) Provide learning media and technology that are helpful for learning.

This guideline was identified during the first cycle of action research. In this cycle, the instructor planned the teaching process by posing questions before class and assessing knowledge to prevent test scores from negatively impacting academic performance. Various applications were employed, with the initial plan involving the use of Kahoot and a Bingo game to engage students in answering questions and reviewing their knowledge before class. Teaching included the use of PowerPoint presentations in conjunction with active learning strategies. Upon reflection, the instructor noted that students enjoyed participating in activities that involved answering questions through applications, playing games, competing, and having the opportunity to win prizes. In subsequent cycles, the instructor continued to implement this teaching approach, making adjustments to the applications to maintain student engagement and introducing other teaching tools to enhance the teaching process. Classroom observations revealed that both instructors effectively utilized media and technology in two primary ways. Firstly, they used Kahoot, Quizzes, Mentimeter applications, and Google Forms to assess students' knowledge before, during, and after the lessons. Quizzes was the application used most frequently by both instructors. Secondly, they employed Microsoft Excel, Microsoft PowerPoint, Google Classroom, Google Docs, and games as teaching tools to enhance students' learning. Microsoft PowerPoint was used by the instructors every week.

3) Use higher-level questions to promote students' thinking processes.

This guideline emerged during the third cycle of action research, based on the instructor's reflections from the first two teaching cycles. In the initial teaching phases, the instructor primarily employed questions to assess students' acquired knowledge. These questions often prompted a 'Yes/No' answer, limiting students' ability to provide explanations or engage in higher-order thinking. However, in the third cycle, the instructor revised the question format, encouraging students to think critically and explain their answers. This change led to students engaging in analytical and critical thinking, demonstrating greater discretion in their responses, and showcasing their ability to apply their knowledge to explain phenomena or predict relationships. In subsequent cycles, the teacher continued to implement this guideline, noticing that learners became increasingly proficient at expressing their knowledge and ideas.

The instructors utilized various forms of questions to achieve three purposes. Firstly, to identify differences through the use of comparative questions; examples of the questions are as follows:

> *"How is a monomer different from a repeating unit?"* (Week 3)
>
> *"From what you learned, what are the differences between the two types of polymerization?"* (Week 3)
>
> *"From your observation, how do different fluids have different viscosities?"* (Week 10)

Secondly, to check learners' concepts and understanding, the following examples of questions were asked:

> *"How does a polymer change the phase?"* (Week 5)
>
> *"If tested at a higher speed, how would the original graph change at normal temperature?"* (Week 7)
>
> *"What techniques can be used to analyze this polymer? Please explain."* (Week 14)

Finally, to encourage further investigation through inquiry-based questions, instructors used questions such as the following:

> *"If all the polymers produced have the same molecular weight, what will be the value of the polydispersity index?"* (Week 4)

"If you have identified the properties of modulus, strength, and breaking point strain from a table, how would you create a graph?" (Week 7)

"What are the main properties of polymers? How can you analyze those properties?" (Week 14)

4) Use authentic assessment and constructive feedback linked with real-life situations to reinforce students' learning and maintain good study habits.
This guideline was discovered during the second cycle of action research. Upon reflecting on the first cycle of teaching, the instructor noticed that students were primarily assessed through pre- and post-class questioning. There was no clear assessment of students' understanding during the learning process, and feedback was lacking. This reflection revealed a problem: instructors could not gauge students' comprehension during lessons, and learners were unaware of the areas they excelled in or those that needed improvement. In the second cycle, instructors adjusted their approach by evaluating students through pre- and post-class questions as well as introducing further questions during class activities and through worksheets. They also provided constructive feedback to students through collaborative work in class and the examination of worksheets. This adjustment allowed instructors to assess students' understanding, and learners gained insight into the areas they needed to develop in their learning. Consequently, this approach continued to be employed in subsequent cycles.
The results of the observations showed that both instructors used a variety of assessment methods to evaluate students' learning performance, as follows.

4.1) Asking questions before, during, and after learning. Examples of the observations are presented below.

"The instructor sought learners' opinions and prior knowledge, gave feedback during class without judgment, and used the Kahoot application to assess students' understanding afterward." (Instructor 1, week 2 observation)

"The instructor asked questions such as 'Do you know any polymer additives?', 'What are the main polymer additives used on airplanes?', and 'What is the purpose of using polymer additives?' During class, students discussed and investigated to find answers. A posttest with seven questions was administered using the Quizzes app after class." (Instructor 2, week 12 observation)

4.2) Providing activity worksheets and assigning tasks to summarize key concepts. Examples of the observations are provided below.

"The instructor gave a group activity worksheet on the mechanical properties of polymers, provided guidance on calculations and unit conversions, and reviewed the work for necessary adjustments. Students then presented their findings to the class." (Instructor 1, week 6 observation)

> *"The instructor assigned a mind-mapping task which was well-executed by the students. The instructor gave individual feedback and suggestions for improvement."* (Instructor 2, week 12 observation)

Part 2: The views of instructors and students on active learning
The results of the instructors' interviews are summarized as follows.
1) The implementation of active learning techniques in the polymer science classroom is highly beneficial for students.

> *"Active learning is beneficial in terms of promoting student participation. In this generation, traditional lectures often fail to engage students, who may disengage and become disinterested in the class."* (Instructor 1, interview)

2) The instructors acknowledged certain limitations to the use of active learning techniques in the polymer science classroom .

- The limitation of providing feedback to students.

> *"It is impossible to provide complete feedback for all students individually; it must be given as a group."* (Instructor 1, interview)

> *"I feel that I'm not yet able to fully manage an active learning class, especially when it comes to providing feedback to students. Within the limited timeframe of 1-2 hours, it's impossible to give feedback to every student in every group."* (Instructor 2, interview)

- The difficulty of organizing students for group work.

> *"Grouping students with different abilities together actually takes time, is rarely done, and difficult to control. Most students prefer to work with friends [who] sit close to each other and choose the members of their group themselves. However, this way of grouping has its advantages, as it allows students to start learning and engaging in activities more quickly."* (Instructor 1, interview)

3) This research project contributed to an improvement in the instructors' teaching competency.

> *"At first, I didn't understand what active learning was. Later, I realized that I had used active learning in my past experiences, but I didn't have much knowledge about it. This research project helped me improve my knowledge and enabled me to think more about teaching activities and feedback methods."* (Instructor 2, interview)

Interviews were conducted with 10 students after the midterm examination and 10 students after the final examination. The students' interview results are shown as follows.
1) The students found active learning to be enjoyable and effective in motivating them to learn science and acquire knowledge in the polymer science classroom.

"Learning this way was fun and helped us to gain more knowledge." (Student 2, interview in the first half of the semester)

"The instructor allowed all students to work in groups so that they could debate, discuss, and understand the content. When I did the group activities with friends, I presented our work and the instructor pointed out where I had made mistakes and where I was still lacking." (Student 4, interview in the first half of the semester)

"The instructor provided us with various tasks and activities, including individual tasks, paired tasks, group work, games, and the jigsaw method. These activities motivated me to learn happily." (Student 7, interview in the second half of the semester)

2) The students enjoyed using learning media and technology such as Kahoot, Quizzes, and games in the class, which helped them review their prior knowledge and better understand the content.

"I like Kahoot where the whole room plays simultaneously, gets excited, has time limits, and knows the order of winners. When the instructor gives rewards, it makes students active." (Student 6, interview in the second half of the semester)

"*The instructor played a Bingo game in class where students filled out their cards with different types of polymers. The instructor provided polymer characteristics, and the students checked their cards. The first to complete a line won a prize, helping them recall their studies and making learning enjoyable.*" (Student 7, interview in the second half of the semester)

3) The students recognize the importance of feedback in active learning in the polymer science classroom.

"In the mind map activity, the instructor collected all student work to provide feedback on the following week, including suggestions such as adding units to certain parts or correcting graphs." (Student 8, interview in the first half of the semester)

"The instructor provided feedback on all student assignments and tasks, pointing out any errors and offering additional resources if needed." (Student 1, interview in the second half of the semester)

4) The instructor informed students about assessment criteria and scores, and allowed them to give feedback on adjusting the ratio of scores or criteria.

"In the first period of class, the instructor informed students about the midterm and final exams, their percentage in the course, and collected scores. Students were also given the opportunity to provide their opinions

on adjusting the exam-to-score ratio." (Student 8, interview in the first half of the semester)

"The instructor discussed the assessment criteria with students during Covid-19 and allowed for adjustments to be made in order to reach a mutual agreement." (Student 2, interview in the second half of the semester)

5) Obstacles and limitations of using active learning in the polymer science classroom, according to student feedback, are as follows.

- Students struggle to follow the instructor's explanations and take notes on all the concepts. Adding more detailed explanations to the slides could help students to follow polymer science concepts more easily.

"Slides had made us understand a lot, but if the slides had too much content for us to write, it made us unable to follow the instructor's explanations." (Student 9, interview in the first half of the semester)

- Students find it more difficult to concentrate when learning online compared to learning in the classroom.

"The obstacle was a lack of concentration while studying online. Online learning requires more concentration compared to in-person learning in the classroom. Live teaching may be more effective in this regard." (Student 1, interview in the second half of the semester)

"I had no concentration when studying at home. I would rather go back to university. At first, it was ok, but then I started not understanding the lessons. I think that studying in the real classroom context, the instructor could explain the concepts better." (Student 6, interview in the second half of the semester)

- Communication during online active learning is not as effective as learning in the classroom.

"In the online platform, the instructor was unable to see the students' faces and thus did not know when they were confused. Even though the instructor explained the concepts in detail, learning in the classroom was better. This is because we could raise our hands for the instructor to see and explain again." (Student 3, interview in the second half of the semester)

"Without Covid, the instructor would have more learning activities. Learning online made communication difficult." (Student 4, interview in the second half of the semester)

"Kahoot and Quizzes were usually given by the instructor. In normal classroom lessons, it was more fun to play and talk with friends. However, during online learning, the instructor sent us the links. It wasn't as fun as

before and we didn't talk as much." (Student 5, interview in the second half of the semester)

- Students faced persistently unreliable internet connections while learning online.

"During Covid, there was a problem with unstable internet. I could not complete the question. Typing words and messages may not be completed. I always forgot to ask the instructor when I had questions." (Student 3, interview in the second half of the semester)

"Internet problems, noise, sometimes studying at home alone would be more stressful, not seeing friends." (Student 8, interview in the second half of the semester)

"The problem was students did not have internet access at home, only telephone internet, which is unstable." (Student 9, interview in the second half of the semester)

Part 3: Students' satisfaction toward learning

According to the results, students were highly satisfied with their learning experience in general, with the assessment and evaluation aspect receiving the highest mean score (M = 4.71, S.D. = 0.76). Similarly, the teaching and learning process aspect also received a high mean score (M = 4.61, S.D. = 0.52), followed closely by the learning media aspect (M = 4.60, S.D. = 0.49). These findings are presented in Table 3.

Table 3: Students' satisfaction toward learning

Items		M	SD	Level of satisfaction
Aspect 1: Teaching and learning process		4.61	0.52	Very high
1.1	The instructors clarified the scope of the content and the learning objectives.	4.76	0.44	Very high
1.2	The instructors arranged the steps for teaching and learning in the classroom.	4.65	0.49	Very high
1.3	Students practiced analytical thinking processes to solve problems in real-life situations or case studies.	4.53	0.51	Very high
1.4	Students linked their prior and new knowledge through their own thinking processes and practice.	4.41	0.62	High
1.5	The instructors used a variety of teaching and learning techniques and activities.	4.76	0.44	Very high
1.6	The instructors encouraged students to participate and be a part of the learning activities.	4.65	0.49	Very high
1.7	The instructors gave students the opportunity to present or comment on learning activities.	4.53	0.51	Very high

Items		M	SD	Level of satisfaction
1.8	The learning activities encouraged students to discuss and exchange their knowledge and opinions.	4.53	0.51	Very high
1.9	The learning activities fostered interaction between students and instructors.	4.65	0.49	Very high
1.10	After learning, students had opportunities to summarize and discuss what they had learned.	4.53	0.51	Very high
1.11	The instructors regularly provided feedback to students.	4.47	0.72	High
1.12	The instructors provided positive reinforcement such as rewards and extra points to stimulate students' learning.	4.76	0.44	Very high
1.13	Technology was integrated into learning.	4.59	0.62	Very high
1.14	The instructors gave students the opportunity to ask questions through various channels.	4.65	0.49	Very high
Aspect 2: Learning media		4.60	0.49	Very high
2.1	The learning media used in the activities are diverse.	4.65	0.49	Very high
2.2	The learning media used in the activities were consistent with the content.	4.53	0.51	Very high
2.3	The learning media used in the activities were consistent learning activities.	4.59	0.51	Very high
2.4	The learning media used in the activities can promote or stimulate students' learning.	4.65	0.49	Very high
Aspect 3: Assessment and evaluation		4.71	0.46	Very high
3.1	The guidelines and methods for measuring and evaluating were clearly explained to the students.	4.71	0.47	Very high
3.2	The criteria for evaluation were consistent with the learning objectives.	4.65	0.49	Very high
3.3	The instructor gave students the opportunity to participate in adjusting the criteria or assessment scores.	4.65	0.49	Very high
3.4	The students were informed of their assessment and evaluation results in order to improve the students' learning process.	4.71	0.47	Very high
3.5	The instructors gave learners the opportunity to participate in self-assessments or peer assessments.	4.71	0.47	Very high
3.6	The instructors gave students the opportunity to reflect on what they had learned.	4.76	0.44	Very high
3.7	The instructors applied a variety of methods for assessing and evaluating learners.	4.76	0.44	Very high

Items		M	SD	Level of satisfaction
3.8	The instructors used technology to assess and evaluate students' learning outcomes.	4.71	0.47	Very high
Overall		4.64	0.49	Very high

6. Discussion

The study's findings offer practical guidelines for implementing active learning in undergraduate polymer science classrooms in Thailand. To promote student participation and cooperation in both online and on-site active learning environments, instructors should use a variety of active learning strategies and techniques that align with students' learning styles. This study's instructors used a range of techniques, such as think-pair-share, group work, role-playing, discussion activities, questioning, and jigsaw techniques, to engage students and facilitate their understanding of polymer concepts. According to research, active learning activities can encourage student participation and enhance teaching and learning (Al-Rawi, 2013; Clark et al., 2023). The benefits of group work activities in promoting students' academic and social abilities are well established. Mixed-ability groups are particularly effective in facilitating learning from peers, with previous research indicating that the most successful groups are those with diverse members and skill levels. Additionally, a clear division of responsibilities within groups is crucial for success (Al-Rawi, 2013; Sandrone et al., 2021; Silberman, 1996). However, this study faced a limitation in that students were not given the opportunity to select their own group members, which can be a time-consuming process. One instructor noted that students preferred to work with familiar peers and may not want to work with less familiar peers. Interestingly, groups comprised of close friends were found to facilitate quicker and more in-depth learning. However, the study by Nardo et al. (2022) suggests that group work can increase students' stress, particularly for those who are less prepared and may feel left out of the group. Therefore, when organizing students into groups, instructors should allocate more time for students to communicate with each other before performing the group work activity. Guiding students on how to work effectively as a team is another way to help them learn collaboratively. In this study, questioning and discussion activities were applied in every class. The instructors always asked questions and allowed the students to discuss and express their thoughts and understanding. Discussions can increase students' confidence and encourage participation in learning. Additionally, discussion activities can help instructors to assess their students' understanding. However, instructors must have the skills to create effective discussion questions (Al-Rawi, 2013; Waldrop, 2015).

Secondly, incorporating learning media and technology is an effective way to enhance the learning experience in the polymer science classroom. In this study, applications such as Kahoot, Quizzes, Mentimeter, and Google Forms proved to be valuable tools for assessing students' knowledge before, during, and after class. In addition to assessment, these tools also fostered student engagement and participation. The interview results revealed that students enjoy learning with the aid of technology and media, as they are growing up in a technology-driven era.

Research suggests that technology and hands-on activities can improve students' learning outcomes and promote critical thinking skills (Giray, 2022; Mosca et al., 2019). Thus, teaching and learning styles in higher education need to evolve to meet the needs of today's students and provide them with meaningful and engaging learning experiences (Kim et al., 2019; Mosca et al., 2019). However, students reported struggling with concentration during online learning, and found the applications used in the online classroom – such as Kahoot and Quizzes – less enjoyable compared to learning in the polymer science classroom. Additionally, unstable internet connectivity hindered their ability to learn efficiently, and communication via online platforms was deemed less effective than in-person learning. These problems had a significant impact on students' ability to learn. One of the instructors also reflected on the challenges of managing an active learning class in an online environment and emphasized the importance of instructors being well-prepared to use learning media and communication effectively.

Thirdly, incorporating high-level questioning can enhance students' critical thinking processes. The instructors employed comparative and conceptual questions to assess students' comprehension. Furthermore, they used questions to introduce the activity and investigation. Such questions motivated students to contemplate what they had learned and solve problems. Although questioning was used frequently in class, questions that challenged students to apply their knowledge to novel situations were seldom used in this study. Questioning is a crucial aspect of learning, not only in active learning classrooms, but in any setting. Questions should be challenging, requiring students to apply their knowledge to explain phenomena or solve problems (Waldrop, 2015). Moreover, the questions or problems should allow students to apply what they have learned to novel situations (Schmidt et al., 2015). However, the difficulty of generating effective questions is a limitation of implementing active learning in the polymer science classroom. Science instructors should collaborate with educators to hone their skills in constructing good questions (Al-Rawi, 2013). Additionally, instructors should avoid calling on students randomly to answer questions or perform activities, particularly in larger science classrooms, since this can cause students anxiety and impede their learning (Cooper et al., 2018).

The final guideline identified from this study is the use of authentic assessment and the provision of constructive feedback, linked with real-life situations, which can reinforce students' learning and help them to maintain good study habits. In the polymer science classroom, the instructors used a variety of assessment methods, including asking questions, summarizing the knowledge with mind maps, using worksheets, observing students' learning behaviors, and examinations. These various assessments allowed students to be assessed according to their actual learning outcomes. Authentic assessment focuses on giving feedback to students, letting them solve problems, and providing opportunities for students to develop and improve their own learning (Henderson et al., 2019; Sokhanvar et al., 2021). Previous research has revealed that science students fear negative evaluations, specifically from their classmates (Cooper et al., 2018). Thus, instructors need to create a good learning atmosphere, promote learning for students, and act as role models in providing constructive feedback. Feedback needs to be well-prepared (Johannes & Haase, 2022; Schmidt et al., 2015), as it affects many dimensions for improving students' learning, including cognitive, self-assessment skills, and motivation (Henderson et al., 2019; Johannes & Haase, 2022). In this study, the instructors always gave feedback to students individually and in each group. As indicated in the interviews, the students have also realized that feedback is important when learning through active learning techniques in the polymer science classroom.

The survey of students' satisfaction with their learning experience yielded high mean scores in all aspects, including the teaching and learning process, learning media, and assessment and evaluation. These findings correspond with the results of students' interviews, in which the participants expressed that active learning was enjoyable and effective in motivating them to learn science. This can be attributed to the well-designed polymer science course, which was created through a collaborative effort between science instructors and educators, with a strong emphasis on active learning principles. The course incorporates a diverse range of activities that encourage student engagement and class discussions. Furthermore, the integration of media and technology serves as a motivational tool for students. Instructors actively provide feedback to help students improve their learning and class participation, creating a conducive learning environment. These characteristics align with the principles of student-centered learning, which prioritize active student engagement and participation in the learning process.

7. Conclusions

This research offers a comprehensive understanding of active learning implementation in undergraduate polymer science classrooms in Thailand, providing practical guidelines for educators. In addition, the study underscores the importance of employing a diverse range of active learning strategies that cater to students' varying learning styles. Techniques such as think-pair-share, group work, role-playing, discussion activities, questioning, and jigsaw methods have proven effective in engaging students and enhancing their comprehension of complex polymer concepts. Furthermore, the integration of learning media and technology has emerged as a powerful tool for enriching the learning experience in the polymer science classroom. However, the challenges associated with online learning, including issues related to concentration and technological hurdles, highlight the vital role of well-prepared instructors who are capable of effectively navigating virtual classrooms. Additionally, the research accentuates the value of high-level questioning techniques to stimulate critical thinking processes. Lastly, the study demonstrates the significance of authentic assessment and constructive feedback linked to real-life situations in reinforcing student learning and study habits. In summary, this research not only offers practical guidelines but also emphasizes the transformative potential of active learning in undergraduate polymer science classrooms. By embracing these guidelines and continuously refining their teaching practice, educators can be empowered to create engaging, student-centered learning environments, preparing students for success in their academic and professional journeys. This study contributes to the ongoing evolution of teaching and learning practices in higher education, particularly in today's dynamic, technology-driven era.

8. Implications and recommendation for further studies

The implications of this research emphasized applying active learning strategies and activities to science courses at the higher education level. Instructors and others who are interested in implementing active learning techniques in their science classrooms can use the four guidelines effectively for both on-site and online forms of learning. In addition, lesson content and time management are equally important when considering active learning. Higher-order questioning skills need to be practiced in order to promote students' critical thinking. Effective questioning and real-life challenges allow students to apply their knowledge and skills to explain new situations and solve a range of problems. Additionally, it is important to create a friendly learning atmosphere, so that students can express their opinions and contribute to effective discussions. This research did not focus directly on instructors' teaching competency and pedagogy when applying active learning in the polymer science classroom. In further studies, the level of teaching competency should be studied and the teaching competency criteria also need to be developed. Moreover, the effects of using active learning techniques on science students' higher-order thinking and life-long learning skills offer further interesting opportunities for future research.

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Ethical considerations

Ethical approval was obtained from Srinakharinwirot University, Thailand (Research ethics number: SWUEC-453/2563E). Informed consent was obtained from the second-year undergraduate students who were the participants in this research.

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