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Calculus Pathways: Hispanic-Serving Institution Perspective

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Abstract: What are the things that need to come together for students to succeed in calculus? Nowadays, students take most of their entry-level mathematics courses using several modes. The first mode is the dual credit pathway, i.e., high school students matriculate as college students and gain college credits. The second mode is taking these entry level mathematics courses in person or online from community colleges. The third mode is matriculating directly as university STEM majors given that some students pass college entrance exams and are then placed in calculus. This paper presents historical exposition about the evolution of the different pathways and describes innovative ways followed by students of varied backgrounds to successfully complete introductory calculus which is controversially considered lately as filtering course for would be STEM majors. Each pathway has pros and cons. With the proper guidance and articulation of the complicated process of transfer of credits from high schools, colleges and universities, the students can easily navigate the path to succeed and move on to finish their STEM degrees. Clear and concise articulation agreements between high school districts and colleges, high school districts and universities, and colleges and universities must be well-established so that certain standards are maintained. This paper elucidates common best pre-calculus and calculus education practices and academic support services to help students navigate and succeed in these courses considered to be obstacles to obtaining a STEM degree.

Keywords: Mathematics, Pathways, Success, Retention, Completion

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Introduction

In an era where STEM education is pivotal to global competitiveness, the traditional calculus sequence has increasingly come under scrutiny for its rigidity and lack of inclusivity. This paper serves as a response to this challenge, aiming to reimagine how calculus is taught, learned, and applied across diverse educational contexts. This work is grounded in the belief that calculus should not be a gatekeeper but a gateway or bridge, i.e., one that opens doors to opportunity rather than closes them. Recent research in mathematics education (Santos-Trigo, 2024) underscores the importance of problem-solving, conceptual understanding, and the integration of digital tools in fostering mathematical thinking (Mesa & Wagner, 2025). These insights inform the design of innovative pathways that prioritize student agency, contextual relevance, and interdisciplinary connections. By leveraging adaptive technologies, culturally responsive pedagogy, and modular course structures, this initiative

seeks to dismantle systemic barriers and promote equity in mathematics education (Bhat, 2023). This article aims to make calculus a dynamic, accessible, and empowering experience instead of a monolithic hurdle. Through case studies, theoretical frameworks, and empirical findings, we explore how innovative calculus pathways can support diverse learners in achieving academic and professional success (Mesa & White, 2021).
The sentence "Calculus should not be a gatekeeper." reflects a growing educational philosophy that challenges the traditional role of calculus as a rigid filter that disproportionately excludes students, especially those from underrepresented or underserved backgrounds from STEM pathways. Instead, this philosophy advocates for restructuring calculus as a supportive, inclusive, and flexible gateway that enables more students to succeed and progress in their academic and professional journeys. Historically, calculus has served as a high-stakes course that determines whether students can continue in STEM majors. Many students, particularly first-generation, low-income, or underrepresented minorities struggle with calculus due to:

- Gaps in prior mathematics preparation
- Rigid course sequences
- Large lecture formats with limited support
- A lack of contextual or applied learning

This has led to high failure and withdrawal rates, discouraging students from pursuing STEM degrees especially in Hispanic Serving Institutions (HSIs). What are some of the published results showing innovative ways to succeed in calculus? At Florida International University, an active learning model replaced traditional lectures with collaborative environments, resulting in an 11% increase in pass rates (Mesa & Wagner, 2025). Another case study at a community college implemented co-requisite support structures, allowing students to enroll in calculus while receiving targeted remediation. These case studies demonstrate the effectiveness of innovative pathways in improving student outcomes.

Calculus Pathways: Past, Present and Future

Traditional Calculus instruction in the U.S. follows a linear sequence: Algebra → Precalculus → Calculus I → Calculus II. This model, largely unchanged since the mid-20th century, often reinforces systemic inequities due to its rigid structure and high attrition rates (Bressoud et al., 2015). At HSIs, these challenges are compounded by underfunded K-12 feeder systems and a lack of culturally responsive pedagogy in postsecondary mathematics. A 2017 report by the Conference Board of the Mathematical Sciences (CBMS) revealed that over 50% of students placed into college-level Calculus I do not earn a C or better, with even higher drop-off rates for students of color (CBMS, 2017). For many Hispanic students, this bottleneck effectively ends aspirations of STEM degrees.

Over the last two decades, calculus education has undergone significant transformation, driven by pedagogical innovation, technological advancement, and a growing emphasis on equity and access. In the early 1990s, calculus was a gatekeeper. It still is. But over the past thirty years, a series of reforms, some bold, others

incremental, have sought to transform this mathematical rite of passage from a barrier into a bridge, especially for Hispanic women and other historically marginalized students in STEM. The 1990s ushered in the "Reform Calculus" movement, catalyzed by the National Science Foundation and a growing awareness that traditional lecture-based instruction was failing large swaths of students. Programs like Harvard Calculus and the Calculus Consortium at Harvard (CCH) emphasized conceptual understanding, real-world applications, and collaborative learning. At the same time, the integration of graphing calculators and computer algebra systems began to reshape classrooms. Yet, as Susan Barton noted in her study of "reluctant reformers," the success of these innovations hinged on faculty buy-in and pedagogical shifts, not just new tools. By the early 2000s, the conversation began to shift from pedagogy to equity. Reports from the National Council of Teachers of Mathematics (NCTM) and the Mathematical Association of America (MAA) highlighted disparities in access to calculus, particularly in high schools serving Black and Latinx students.

The College Board's expansion of AP Calculus was a double-edged sword: while it increased access, it also reinforced tracking systems that often excluded students of color from advanced math pathways. Meanwhile, HSIs began piloting summer bridge programs and peer-led team learning models to support calculus readiness and retention. The 2010s saw a paradigm shift: from a singular focus on calculus to multiple mathematics pathways. The Dana Center's Launch Years Initiative and the Carnegie Foundation's Statway and Quantway programs argued that not all STEM careers require calculus, and that forcing all students through it was both inequitable and inefficient. Still, for those pursuing engineering, physics, or computer science, calculus remained essential. HSIs responded with culturally responsive curricula, co-requisite models, and faculty development initiatives aimed at dismantling the "weed out" culture that disproportionately affected Hispanic women. Today, equity is no longer an afterthought, it's the design principle. The COVID-19 pandemic exposed and exacerbated educational inequities, prompting institutions to rethink everything from placement exams to instructional delivery. The most promising reforms are those that center student identity and lived experience. At the University of Texas Rio Grande Valley, for instance, calculus courses now incorporate community-based data and bilingual instruction. CSU Dominguez Hills offers a STEM Summer Bridge that blends academic prep with cultural affirmation. Yet, as David Bressoud of the Dana Center warns, the "problematic role of calculus as gatekeeper persists". Only 38% of high schools serving majority Black and Latinx students offer calculus at all.

STEM Education of Hispanic Women

Calculus education for Hispanic women in the United States sits at the intersection of multiple systemic challenges: underrepresentation in STEM, gender bias in mathematical environments, and socioeconomic barriers disproportionately impacting Latinx communities. While the national conversation around increasing women's participation in STEM fields has gained traction, Hispanic women remain critically underrepresented. In 2021, they earned only 3.5% of bachelor's degrees in engineering and 4.6% in computer sciences, despite making up more than 9% of the college-age population (National Science Foundation [NSF], 2023). The bottleneck of Calculus I, often the first STEM-intensive hurdle remains a decisive moment in academic attrition for many Hispanic women. Multiple studies have underscored how gendered and racialized experiences within

math classrooms affect persistence. Hispanic women contend with stereotype threat, a scarcity of role models, and culturally unresponsive pedagogy that can undermine their sense of belonging in STEM spaces (Crisp et al., 2009; Rincón & George-Jackson, 2020).

In traditional lecture-based calculus courses, where competition and abstraction dominate, the pedagogical structure often alienates students who thrive on collaboration and application, learning preferences disproportionately reported by women and students of color (Boaler, 2016). A revealing 2016 study by Ellis, Fosdick, and Rasmussen found that women, including Latinas, are significantly more likely than men to leave the calculus sequence, not because of lack of ability, but due to lower self-assessed competence even when performance is equivalent. For first-generation Hispanic women navigating unfamiliar academic systems, this confidence gap is further exacerbated by cultural and linguistic dissonance in classroom norms.

The Promise of Hispanic-Serving Institutions (HSIs)

Despite these obstacles, Hispanic-Serving Institutions are emerging as critical laboratories for educational innovation. With missions rooted in serving underrepresented populations, many HSIs have implemented targeted reforms that address the cultural, cognitive, and economic realities of their student populations. One such approach is the co-requisite support model, increasingly used in institutions like California State University, Los Angeles (CSULA). Rather than forcing students to complete multiple remedial math courses before attempting Calculus I, students are enrolled in calculus alongside mandatory support sessions that contextualize concepts and offer just-in-time remediation.

A study by Martínez and Salazar (2021) at CSULA showed a 26% increase in pass rates among Latina students over three years, attributable to these co-requisite reforms. Other institutions, such as the University of Texas Rio Grande Valley (UTRGV), have piloted asset-based placement systems, replacing traditional placement tests with multi-metric evaluations (including GPA, teacher recommendations, and student essays) that better reflect students' potential. UTRGV also integrates culturally relevant pedagogy into STEM instruction, such as including examples from Mexican-American agriculture and public health in calculus problems—a strategy shown to enhance engagement and identity alignment (Gómez, personal communication, 2024). Additionally, the Latinas in STEM Collaborative at Florida International University (FIU), another large HSI, provides mentorship programs linking undergraduate calculus students with Latina professionals in engineering and analytics. These programs mitigate attrition by addressing psychosocial needs: belonging, resilience, and representation (Villanueva & Gonzalez, 2022).

Implications for Job Prospects and Economic Mobility

The impact of these efforts extends beyond academia. Hispanic women in STEM fields face a significant wage gap compared to their White and male counterparts. However, for those who persist through calculus and attain STEM degrees, the returns are substantial. According to the U.S. Bureau of Labor Statistics (2023), median

weekly earnings for STEM occupations hover around $1,900, compared to $1,200 for non-STEM fields. This differential has profound implications for intergenerational economic mobility, particularly for Hispanic women who are more likely to support extended family networks. Yet the underrepresentation of Hispanic women in high-tech and engineering roles means that much of this potential remains untapped. Innovations in calculus education at HSIs if scaled and supported offer a compelling strategy for closing these opportunity gaps. But systemic investment is required. Without increased funding, expanded mentorship, and policy-level commitment to equity in STEM, the burden will continue to fall on individual students and under-resourced institutions to bridge the divide.

Analysis of Employment and Wage Trends

The employment projection chart (Figure 1) shows a steady increase in the number of Hispanic women entering STEM fields over the next decade. This growth reflects broader national trends in STEM workforce expansion and the increasing participation of underrepresented groups. However, the pace of growth also suggests that continued support and targeted interventions are necessary to sustain and accelerate this trajectory. The wage chart (Figure 2) highlights the substantial earning potential in STEM careers, with median wages ranging from $76,000 to $95,000 annually. These figures reinforce the economic imperative of supporting Hispanic women through the calculus pipeline, as success in this foundational subject opens doors to high-paying, high-growth careers. The disparity in wages across disciplines also suggests the need for career guidance and mentorship to help students navigate their options effectively.

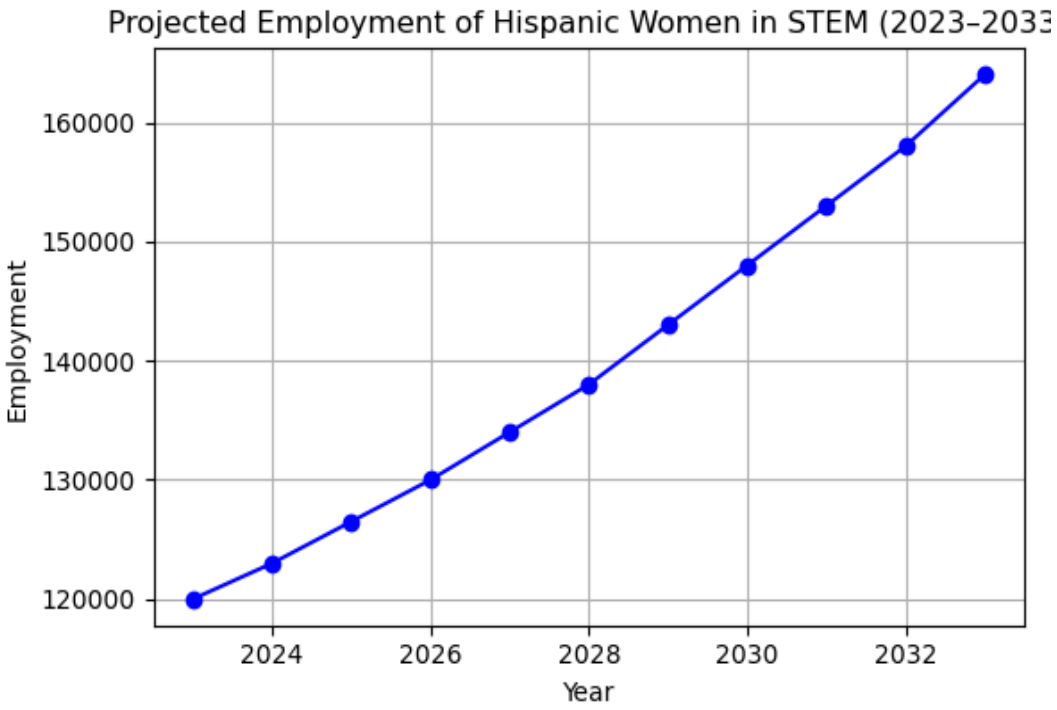

Figure 1. Projected employment of Hispanic women in STEM from 2023 to 2033.

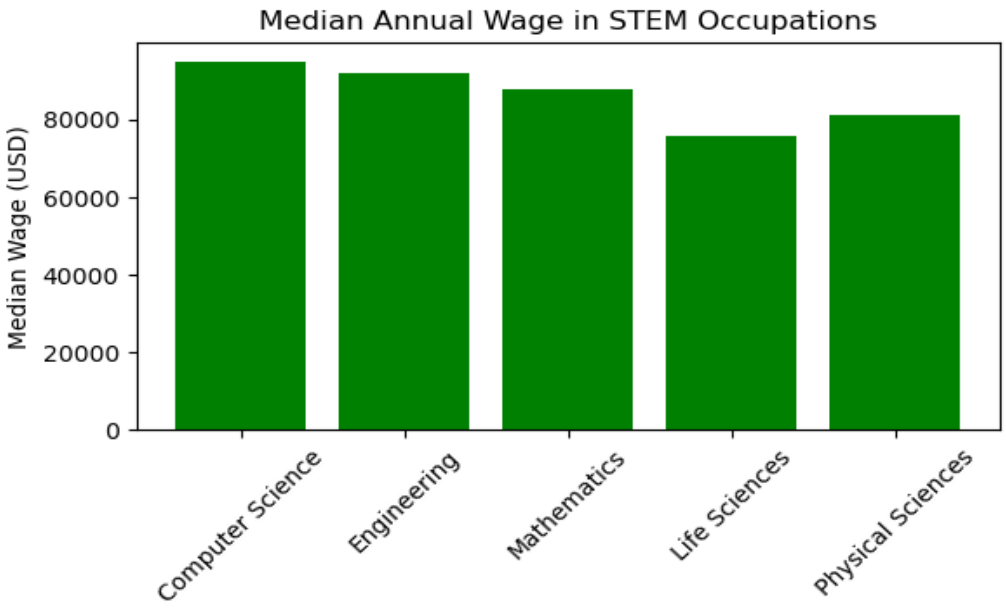

Figure 2: Median annual wages in various STEM occupations.

A 2023 report titled *Staying the Course* by Just Equations highlights that nearly one million students attempt college-level calculus or precalculus each year without success, disproportionately affecting students from underrepresented backgrounds. For Hispanic women, these outcomes are shaped by a lack of culturally responsive pedagogy, limited access to rigorous high school math preparation, and underrepresentation in STEM faculty and mentorship roles. However, Hispanic-Serving Institutions (HSIs) have begun to implement innovative strategies to address these disparities. For example, the California State University (CSU) system has adopted reforms to reduce reliance on remedial math and instead integrate co-requisite support models. These models allow students to enroll directly in college-level calculus while receiving additional academic support, thereby accelerating progress and improving retention.

Innovative Approaches in HSIs

Several HSIs have pioneered culturally affirming and equity-driven approaches to calculus education:

- **Contextualized Curriculum:** Institutions like CSU Fullerton and University of Texas Rio Grande Valley have embedded real-world, culturally relevant problems into calculus coursework to increase engagement and relevance for Hispanic students.
- **Bridge and Summer Programs:** Programs such as the *Math Summer Bridge* at HSIs provide intensive preparation and community-building opportunities before students begin college-level calculus.
- **Faculty Development:** Professional development initiatives focused on inclusive teaching practices have been instrumental in reshaping classroom dynamics and expectations.

• **Peer Mentoring and Learning Communities:** These support structures foster a sense of belonging and academic confidence, which are critical for persistence in STEM.

Discussion & Conclusion

Calculus serves as a critical gateway for STEM (Science, Technology, Engineering, and Mathematics) majors, yet its role as both a bridge and barrier has provoked national concern—especially at Hispanic-Serving Institutions (HSIs), where equity and representation remain pressing issues. With more than 570 HSIs across the United States enrolling over 2 million Hispanic students, the evolution of Calculus pathways in these institutions offers a compelling lens through which to assess the broader movement toward inclusive, effective mathematical education (Excelencia in Education, 2023). Graduates who overcome the calculus hurdle and pursue STEM degrees enjoy strong job prospects. According to the U.S. Bureau of Labor Statistics, occupations requiring advanced math skills—such as data science, engineering, and actuarial science—are projected to grow significantly through 2033. However, Hispanic women remain underrepresented in these fields, suggesting a need for continued investment in targeted support and career development initiatives. Moreover, the intersection of gender and ethnicity often results in wage disparities and limited advancement opportunities. Addressing these inequities requires not only academic preparation but also systemic change in hiring practices, workplace culture, and mentorship availability.

Innovative calculus pathways over the past two decades reflect a broader shift toward student-centered, inclusive, and conceptually rich mathematics education. By embracing alternative frameworks like infinitesimals, redesigning curricula to meet diverse needs, leveraging technology, and prioritizing equity, educators are reshaping the calculus experience for the 21st century. Three decades of reform have yielded progress—but not parity. For Hispanic women, the calculus classroom remains a contested space: one of potential and peril. The challenge now is not just to reform calculus, but to reimagine it—as a space of inclusion, empowerment, and possibility. The findings suggest that innovative calculus pathways can significantly enhance student success and retention in STEM fields. Key factors include the alignment of curriculum with student needs, the use of technology to personalize learning, and the creation of inclusive classroom environments. Challenges remain, particularly in scaling these innovations and ensuring faculty buy-in, but the potential benefits are substantial. This article offers a blueprint for transforming calculus education. By centering equity, engagement, and evidence-based practices, this work contributes to a more inclusive and effective STEM education landscape. Future research should explore long-term impacts and strategies for institutionalizing these innovations.

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Social Media Attitudes and Purposes Among Adolescents: Exploring Digital Engagement in Secondary Education

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Abstract: This study examines secondary school students' purposes for using social media and their attitudes towards its use. Conducted with 60 students from Iyas Selcuklu Secondary School in Isparta, Turkey, the research used a survey to gather data on social media habits, including usage frequency, time spent, and preferred platforms. Findings reveal that social media is primarily used for sharing photos, music, and entertainment, with significant differences in usage patterns based on gender and socioeconomic status. Male students were found to use social media more frequently than female students, while those with higher incomes reported greater access and longer usage durations. The most popular social media platforms among participants were Instagram and Facebook. The study also suggests that social media has become integral to students' lives, influencing daily habits and providing an online environment for socialization. These findings highlight the growing role of social media in adolescents' lives and underline the need for guidance on responsible usage, particularly as social media usage continues to rise among young people. Recommendations include integrating social media literacy into educational curricula to help students develop healthy, balanced usage patterns.

Keywords: Social media, Secondary education, Usage patterns, Student attitudes, Social media literacy

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Introduction

When we say social media, one of the first words that comes to mind is sharing. Social media is an online network platform that allows people to communicate, and allows us to be in real time with one or more individuals in different communication channels (Kaban, 2021a, 2021b; Ozturk & Ozturk, 2022). Since the day humanity came into being, communication has been the greatest and most important need of people. The element of curiosity in people, the desire to prove themselves to society, the desire to learn what other people do and compare them to their own lifestyle and to show themselves higher than where they are at that moment are among the basic characteristics that make a person human. Based on this situation, people have invested in communication technology for centuries. When we look at the history of communication, in Web 1.0 technology, people were only receiving information, that is, reading it. With Web 2.0, mutual communication over the internet, network sharing, in short, people started to be able to do many things that they can do in their

daily lives in a virtual world. When we observe today's internet tools, we see that social media applications attract more attention from people. Social media pages and applications, social media tools, sharing platforms have an effect on people that cannot be ignored. The fact that social media provides individuals with the opportunity to express themselves and reveal their preferences in an online environment makes it different and popular (Evans, 2008).

The first step taken towards popularizing these opportunities and people was the online social networking site known as sixdegrees.com. With the establishment of Facebook in 2004, social media and communication took on a different dimension. In the master's thesis titled “Web 2.0 and Virtual Socialization: The Facebook Example” conducted by Ergenç (2011), it was concluded that 59% of the participants spent more time than usual on Facebook and disrupted their routine work, and 48% stated that they felt much more comfortable on Facebook than in real life. It was observed that nearly 73% of the participants visited more than one Facebook account every day. As a result, it was stated that Facebook had a large place in our daily lives and that those who used it had become accustomed to it.

Argın (2013), in his master's thesis titled "Examination of Middle School and High School Students' Attitudes Towards Social Media", wanted to determine the attitudes of students towards using social media and to show whether there are various variables that lead students to use social media. He conducted his study with 735 students in the 8th, 9th, 10th, 11th and 12th grades of public schools in Çekmeköy district of Istanbul in the 2012-2013 academic year. When the results of the study are examined, it is seen that the students' desire to use social media is high and they develop positive thoughts towards using social media, the students studying in middle school have a higher desire to use social media than the students studying in high school, and the students' desire to enter social media decreases inversely as their grade level increases, i.e. as they grow older. In this context, assuming that people use social media the most during their childhood, which is the most important period of their development, we can think that social media tools are one of the most important effects of human development and character formation. This study was conducted to determine the social media habits of secondary school students, how much they use social media, and to what extent it affects their lives.

In this research, answers to the following questions will be sought.

What are their thoughts on social media?
Do thoughts about social media vary by age, gender and other demographic characteristics?
Which tools are used and how often when using social media?
Does the process of using social media contribute to changing thoughts?
Is there a role and impact of the environment on social media use?

Social Media

In 2007, Clear Swift officials conducted a comprehensive study to determine the extent of social media use and reached the following conclusions. 83% of American employees use the devices they use in the office to access

social media. 30% of office workers in the US and 42% of office workers in the UK admitted that they shared conversations that took place in the workplace that day with each other using social media tools (Bostanci, 2010).

While a person is communicating with another person on social media, they can also communicate with another individual at the same time. Although this situation seems very complicated, it also explains the ease of use of social media. While using social media, we can be in touch with people using another social media at the same time. In other words, unlike daily life, we can be in two different environments at the same time and share two different types of information. This situation worries some researchers when considered as the future. Online social networks are at the heart of some popular websites. As technology develops, people design more web applications and increase their interactions with each other. This also shows that social media plays an important role in personal and online interaction (Mislove, 2007).

Social networks vary in terms of size and heterogeneity . Small homogeneous groups are groups where people share their daily conversations and daily situations, mostly in rural areas and settlements with a population of less than two thousand. On the other hand, three types of ties can be mentioned in social media. The user's action also allows the user's friend to be influenced by the user and to act in the same way. It is the liking of people for the same things. In other words, people can establish friendly friendships with individuals who reflect themselves and have similar behaviors. External factors can be the main reasons for both two people who are friends and their actions. An example can be given when two people who love the same music share the same music on a music sharing site.

In addition to all these, individuals can also turn to social media according to the psychological factors they are in or the feelings they are experiencing at that moment. Individuals hide their real identities and create new identities in the virtual world to talk to people from different cultures, exchange music and make friends (Argın, 2013).
Social media applications or tools affect individuals' material, political and cultural lives. Places visited, clothes worn, drinks consumed and many elements of daily life are instantly followed via social media. Rapidly developing technology also rapidly directs individuals' social lives. New communication platforms have changed many areas from our homework habits to the way we meet people to the way we read books. In the simplest example, while individuals used to communicate face to face while spending their free time, today this has turned into surfing on social media applications.

Dellaloğlu emphasizes that social media is so important that it necessitates individuals to reconsider their communication with each other and explain these relationships with new concepts. In social media, which we interpret as 'distanced proximity', those who are far away are now very close to us, and those who are close to us are just as far away. We can be everywhere at once by using our option of remaining equally distant from the people around us (Dellaloğlu , 2015). Therefore, in order for the created content to reach the target audience, the right communication channels must be used and the platforms on which it will be distributed must be

determined very carefully.

People use social networks for different reasons according to their personal needs and demographic characteristics. The purposes of individuals who are members of social media sites to use that site vary depending on the reason for the site being established. In addition, usage among friends (Boyd & Ellison , 2007), accessing information (Park & Kim, 2013) and entertainment (Lin, Hoffman , & Borengasser , 2013) are slightly more prominent than other factors. With the developing technology, today's youth, adolescents and middle-aged individuals see social media as the main source of communication (Ahn , 2011). According to a study conducted by Lenhart , Purcell , Smith, and Zickuhr (2010), approximately 73% of young people in the USA aged between 12-17 actively use social networks.

It is a matter of detailed discussion how the ever-developing technology can affect the lives of students and the young generation. Some researchers suggest that social media applications such as blog writing and online games can be used to develop students' learning skills, and that social media will become widespread for academic use with the developing technology rather than for spending time (Clarke, 2009). The results of the observations and research conducted show that social networks contribute significantly to middle school and high school students' search for their own identities and their acquisition of the century skills of the century we live in (Wang et al., 2011). Sistek-Chandler (2012) listed the positive features of social networks as having the potential to help shy students connect with others and develop positive relationships with their peers, and to provide students with more opportunities to produce and share ideas. Hieftje (2009) states that social networks provide an environment for young people to express themselves, and that young people feel comfortable in this environment.

Method

Research Model

“Descriptive research model” was used because it would be the most appropriate example for this research . The survey model is a research model that aims to describe a situation that occurred in the past or existed or a situation that exists now as it is. The individual, object or all assumptions that are the subject of the research are defined as they are in their own conditions. In no case or assumption can the change in the situation they are in be affected or determined. The survey technique was used to collect the research data.

Data Collection Tool

The study . These items, which were created to determine the purposes of social media use, were determined by taking the example from Bostancı (2010) research. In the study, the “Social Media Attitude” survey developed by Argın (2013) was used to measure students’ social media attitudes. The survey consists of 23 questions and was created in a way that gender status was asked under the variables and how many times a day they use social media channels under the other heading. The survey included the options “a few times a day, once a day, a few

times a week, once a week, a few times a month". In the 23-question survey, students were asked to choose one of the following options: " Strongly Disagree", "Disagree", "Undecided", "Agree", "Strongly Agree" .

Analysis of Data

While examining and evaluating the data in the research, the SPSS program, which allows us to make statistical analyses, will be used and all data will be entered into the SPSS program according to the surveys taken from the students.

Working Group

Iyas Selcuklu Secondary School affiliated to the Ministry of Education in Isparta province in the 2017-2018 academic year . The research was applied to 60 students. The survey used in the general screening model was applied in the research.

Table 1. Demographic characteristics of the surveyed students

		f	**%**
Gender	Male	33	55.0
	Woman	27	45.0
Class	6th grade	31	51.7
	7th grade	14	23.3
	8th grade	25	25.0
Income Level	low	2	3.8
	middle	47	88.7
	high	4	7.5
Total		**53**	**88.3**

When Table 1 is examined based on the survey data, it is determined that a total of 60 secondary school students, 33 male and 27 female, participated in the study. It was determined that 31 of the students participating in the survey were 6th grade, 14 were 7th grade, and 25 were 8th grade students. However, when the income level of the students participating in the survey was examined, it was determined that 2 of the students had low income levels, 47 had middle income levels, and 4 had high income levels.

Table 2. Demographic table showing whether there is a social media account or not

		f	**%**
	Yes	51	85.0
Social media usage	No	9	15.0
Total		**60**	**100.0**

When Table 2 was examined based on the survey data, it was determined that 51 out of 60 students were members of social media sites and 9 students were not members of social media.

Results

In this section, survey questions were asked to 6th, 7th and 8th grade students at Iyas Selcuklu Secondary School and the students' attitudes towards social media will be examined according to the answers given.

Table 3. Distribution of social media usage frequency of students participating in the study

		f	%
Using Social Media Frequency	More than once a day	8	13.3
	Once a day	14	8.3
	More than once a week	5	23.3
	Once a week	22	36.7
	A few times a month	11	18.3
Total		**60**	**100.0**

, the number of students who use the Internet more than once a day is 8. Those who use the Internet once a day are 14, those who use the Internet more than once a week are 5, those who use the Internet once a week are 22, and those who use the Internet a few times a month are 11.

Table 4. Distribution of social media usage frequency of students participating in the study according to gender

Groups	**N**	**SS**	**Mean**	**Shallow**
Male	27	1,469	2.27	,000
Girl	33	1,281	2.19	

When Table 4 is examined, the distribution of internet usage frequencies according to gender variable is determined. According to the T test, Table 4 shows the frequency of internet usage. Since the value is ,000, there is a significant difference in the gender factor according to the frequency of internet use. As a result of the explore analysis, it was determined that the averages of male students were higher than the averages of female students. In other words, male students use the internet more frequently than female students. Considering these observations, it can be interpreted that male students spend more time on the internet than female students, which causes them to surf more.

Table 5. Distribution of social media usage frequency of students participating in the study according to their grades

Groups	**N**	**SS**	**Mean**	**Shallow**
6th Grade	31	1,261	2.45	

7th Grade	14	1,092	2.50	,395
8th Grade	25	1,598	1.53	

Table 5. When the internet usage frequency of the students participating in the study is examined according to their classes and according to the Anova test results, the value was found to be .395 . Based on this observation, there is no significant difference between the classes. In other words, the duration of students' internet use does not vary according to their classes.

Table 6. Distribution of social media usage frequency of students participating in the study according to their income levels

Groups	**N**	**SS**	**Mean**	**Shallow**
Low	2	,000	1.00	
Middle	47	1,385	2.32	,021
High	4	,577	,50	

Table 6. When the frequency of internet use of the students participating in the study was examined according to their income levels and the Anova test was performed, the sig value was found to be .021 . According to the research results, there is a significant relationship between the frequency of internet use according to income level. Based on these results, we can say that students with high income levels spend more time on the internet than students with low income levels.

Table 7. Findings regarding the time spent on social media by students participating in the study

		f	**%**
	5-10 Minutes	20	33.3
	11-30 Minutes	16	26.7
Social media Usage	31-60 Minutes	15	25.0
Duration	61-120 Minutes	2	3.3
	121 minutes and more	17	11.7
Total		**60**	**100.0**

When Table 7 is examined, the time spent on social media by the students participating in the research when they entered social media was reached. According to these results, it was determined that there were 20 students who spent 5-10 minutes, 16 students who spent 11-30 minutes, 15 students who spent 31-60 minutes, 2 students who spent 61-120 minutes and 17 students who spent 121 minutes or more on social media.

Table 8. Distribution of time spent on social media by students participating in the study by gender

Groups	**N**	**SS**	**Mean**	**Shallow**
Male	27	1,083	1.41	,032
Girl	33	1,034	1.55	

When Table 8 is examined, the distribution of the time spent by the students participating in the research on social media according to gender is reached. According to the T test, the sig value was determined as .032 . Therefore, it was determined that there was a significant difference between the time spent on social media and gender. The time spent on the internet by male and female students varies due to their gender differences . Therefore, we can say that male students spend more time on the internet or social media than female students.

Table 9. Distribution of time spent on social media by students participating in the study according to grades

Groups	**N**	**SS**	**Mean**	**Shallow**
6th Grade	31	1,057	1.58	
7th Grade	14	1,008	1.36	,101
8th Grade	25	1,121	1.40	

When Table 9 is examined, the distribution of the time spent on social media by the students participating in the research according to their classes is reached. In order to determine whether there is a significant difference between these two variables, One-way Anova test was performed and the sig value was determined as ,101 . According to the data determined from the Sig value, there is no significant relationship between the time students spend on social media according to gender. In other words, there is no change in the time spent according to the variability of the classes.

Table 10. Distribution of daily time spent on social media by students participating in the study according to income level

Groups	**N**	**SS**	**Mean**	**Shallow**
Low	2	1,301	1.36	
Middle	47	1,120	1.49	,097
High	4	,577	2.50	

Table 10 is examined, the differences in the time spent by the students participating in the research on social media according to their income status were investigated.

Table 11. Findings regarding the most preferred social media platforms by the students participating in the study

Variables		**f**	**%**
Most preferred social media platform	Facebook	17	28.0
	Instagram	21	35.0
	Twitter	6	15.0
	YouTube	15	25.0
	Tumblr	1	1.7
Total		**60**	**100**

The Sig. value was determined as .097 . According to this sig value, there is no significant relationship between

the time spent and the income level. Based on this result, we can say that there is no connection between the variability of the time spent on the internet according to the income level.

When Table 11 is examined, the most used platforms on social media by the students participating in the research have been reached. According to these results, 17 students use Facebook, 21 students use Other social media platforms, 6 students use Twitter , 15 students use YouTube and 1 student uses Tumblr among the most preferred social media platforms . After the information that Facebook's data was stolen and served to private sectors emerged recently, Facebook shares fell rapidly and many users closed their accounts. Therefore, the most used social media platform has recently been updated to Instagram . Many people state that Instagram is more useful than Facebook. It is a finding we expected that Instagram will be in first place as a result of this research .

Conclusion

When articles and theses on the purposes of using social media and attitudes towards social media are examined, the general result that emerges is that these studies are generally conducted and examined among groups of people of all ages. Although researchers mostly focus on the gender of the participants in the studies, they also examine the age, class and income levels of the students. The aim of this data study is to reveal whether the factors affecting the purposes of using social media and attitudes towards these in secondary school students show significant differences depending on gender, age, class and income levels.

Internet usage has started to be used actively by individuals all over the world, including our country. According to the data analysis obtained from Digital 's 2016 report, 58% of the Turkish population actively uses the internet. 77% of internet users connect to the internet from mobile phones, tablets and computers every day. As technology develops and people's purchasing power increases, the number of individuals connecting to the internet will increase in the future. Of the middle school students participating in the research, 40.8% connect to the internet every day, 24.4% 1-2 days a week, 14% 3-4 days a week, 9.8% 1-2 days a month and 11% 3-5 days a month. According to these data analyses, it is seen that the young generation is starting to use the internet more and more each passing day. As a result of the analysis conducted to determine the differentiation status of the internet usage frequency of the students participating in the research according to the gender variable, it was found that the average of male students (Mean = 2.38) is higher than the average of female students (Mean = 2.12). Considering the significance level of "$p < 0.05$", the $p=0.03$ value found shows that the difference between the two groups is significant. In this case, it shows that males use the internet more frequently for a certain purpose or purposes. When these data analyses are taken into consideration, it would be positive to keep the time male students spend on the internet under control so that it does not affect them negatively.

According to Tanrıverdi (2012) research, male students use the internet more than female students. In their studies on university students, Batıgün and Kılıç (2011) also show that male students use the internet more intensively than female students. Similarly, in my project, male students use the internet more than female

students. Shiftdelete.com conducted a study in February to analyze the most used social media channels in 2018. According to the results of this study, the most used social media network in the world and in Turkey was Facebook with a remarkable rate of 75.49%.

There is a surprise in the second place. The most used social media network in the world is Pinterest . This application, which is not used much in our country, has a usage rate of 10.04%. The usage rate of Twitter, which is one of the most popular social networks in our country , remained at 5.47%. YouTube usage is at 5.08% worldwide. Instagram , which is one of our indispensables, has a usage rate of only 1.84%. When we look at our own analysis according to these results, we see that the most common social media network among middle school students is Instagram . Based on this data, we can say that the young population uses Instagram more, the middle age population uses Facebook and the elderly population uses Facebook.

Recommendations

When the research results are observed, it is seen that students use social media mostly to share pictures, music and to spend time. Students' active use of social media and learning how to use it will make their future lives easier. Another result obtained from the research is that students with high income levels use social media more frequently than students with low income levels. The main reason for this is likely to be that high-income students have access to technological devices such as computers, phones, etc. at a younger age. Since it is known that children can access all kinds of information over the internet at a young age, children should be kept under surveillance against harmful factors.

This study is a quantitative study conducted on secondary school students. Likewise, this study can be supported with qualitative data in addition to quantitative data. Considering that with developing technology, primary school students can also access technological tools and many individuals have social media accounts set up by their families when they were children, this study can be conducted for primary school students as well. At a time when teachers are in a guiding position for students, this study can be conducted with teachers within the same school and students' social media usage can be investigated according to the teacher's social media usage. This study was conducted at Iyas Selcuklu Secondary School. The study can be conducted at surrounding schools as well, and a deeper analysis can be conducted with a general study throughout the province. Argin (2013) scale was used in this study. This scale can be developed and more accurate data can be used to reach definitive analyses.

In this study, students' classes, genders and income levels were generally observed and analyzed. Research can be conducted with different demographic characteristics. Based on all the analyses, an internet usage survey can be conducted by region and then throughout Turkey, and projects can be made for students based on this data.

This was conducted with 60 students in a given middle school. By increasing the number of students, comprehensive analyses can be made. In this data and other studies examined, they were generally conducted at

the student level. In a new study, studies can be conducted on the social media habits and attitudes of working individuals or unemployed people or people in the middle and older age groups. All studies can be combined to create a general Turkey portfolio .

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SLR: Analysis of the Application of a Guided Inquiry Learning Model to Improve Students' Critical Thinking Abilities in Science Learning

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Abstract: The guided inquiry learning model is a learning model that has the potential to improve students' critical thinking abilities. Guided inquiry is a learning model designed to train students to investigate problems and solve them based on facts. This research aims to examine the effectiveness of the guided inquiry learning model on students' critical thinking skills in science subjects. The methodology in this research uses Systematic Literature Review (SLR) with the help of PRISMA (Preferred Reporting Items for Systematic Reviews and MetaAnalyses). The scientific articles used as research data were 40 articles originating from international journals indexed by Scopus. Then it was reviewed again based on school level, namely upper secondary school level, as many as 12 articles were listed. Article validation is carried out by considering articles that can be accessed freely, the quality of research methodology, the topic of the article, and references in the last 5 years. The data collection technique uses descriptive analysis. So based on the literature study that has been carried out, this guided inquiry learning model is very effective in improving students' critical thinking abilities.

Keywords: Guided Inquiry, Critical Thinking, Science

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Introduction

In the era of Industrial Revolution 5.0, education faces big challenges to create human resources that are able to adapt to technological developments (Wenno et al., 2022) Development science and technology are very rapid

(Busaka et al., 2022). In the 21st century, there are 4 skills that generation z needs to have, namely critical thinking, creativity, collaboration and communication (Aiman et al., 2020). One of them, critical thinking, involves a systematic and directed thought process to form beliefs and take organized action such as problem solving, decision making, analysis and research (Hake, 1998).

These skills not only help students in solving complex problems, but also enable them to think logically and make informed decisions. In the context of physics education, critical thinking is very necessary to understand abstract concepts and apply them in various real situations (Fitriyah & Ramadani, 2021). However, in reality, the current education system still tends to be less effective in developing students' critical thinking skills. Teachercentered learning with conventional teaching methods often makes students passive and less involved in the learning process (Phonna et al., 2020). This results in students' low critical thinking abilities, especially in lessons that require a deep understanding of concepts such as physics. The guided inquiry learning model is one solution to overcome this problem. This model involves students actively in the process of searching and discovering knowledge through data collection and hypothesis generation (Putri & Syafriani, 2020). Guided inquiry is a 2 learning model designed to train students to investigate problems and solve them based on facts (Aregehagn et al., 2022).

In this model, students are encouraged to develop their critical thinking skills by discovering new concepts independently and linking them to the knowledge they already have (Phonna et al., 2020). In physics learning, guided inquiry can help students to better understand physics concepts through a process of exploration and investigation (Alzahrani & Alfadhli, 2023). Based on the literature that has been searched, research shows that the application of the guided inquiry model can significantly improve students' critical thinking skills. For example, research by Phonna et al. (2020) found that the use of guided inquiry-based practicums on Newton's law concepts significantly improved students' critical thinking skills compared to the use of conventional verification practicums (Phonna et al., 2020).

Likewise, research by Kurniawan and Syafriani (2021) shows that guided inquiry-based e-modules integrated with ethnoscience can improve students' critical thinking skills in learning physics (Kurniawan & Syafriani, 2021). Based on analysis and empirical evidence, it can be concluded that the guided inquiry learning model is very effective in improving students' critical thinking skills. This model not only makes students more active and involved in the learning process, but also helps them develop the ability to think deeply and critically. Therefore, the integration of the guided inquiry model in the educational curriculum is highly recommended to create a generation that is ready to face the challenges of the Industrial Revolution 4.0. This literature study aims to examine the effectiveness of the guided inquiry learning model in improving students' critical thinking skills in science learning.

Method

This research method uses methods Systematic Literatur Review (SLR) with help Preferred Reporting Items for

Systematic Reviews and Meta-analyse (PRISMA). The SLR method can identify journals systematically, which in each process follow predetermined steps or protocols. The first step in the SLR method is to determine the research object. Data collection techniquesThe data used in this research comes from secondary sources such as articles with other relevant sources through the help of Scopus. The journals and articles studied in this writing are based on the last 5 years published from 2019 to 2024. Search for journals and articles using keywords, namely guided inquiry learning model, critical thinking skills and science.

Data analysis was carried out in three stages, namely grouping, unification and identification. First, in the grouping stage, relevant literature is arranged based on the subject matter after going through a review process first. Then, in the unification stage, the literature results are compiled briefly but coherently. Finally, in the identification stage, relevant and important problems are reviewed and analyzed to produce scientific writing. This can be seen in the prism flow diagram below:

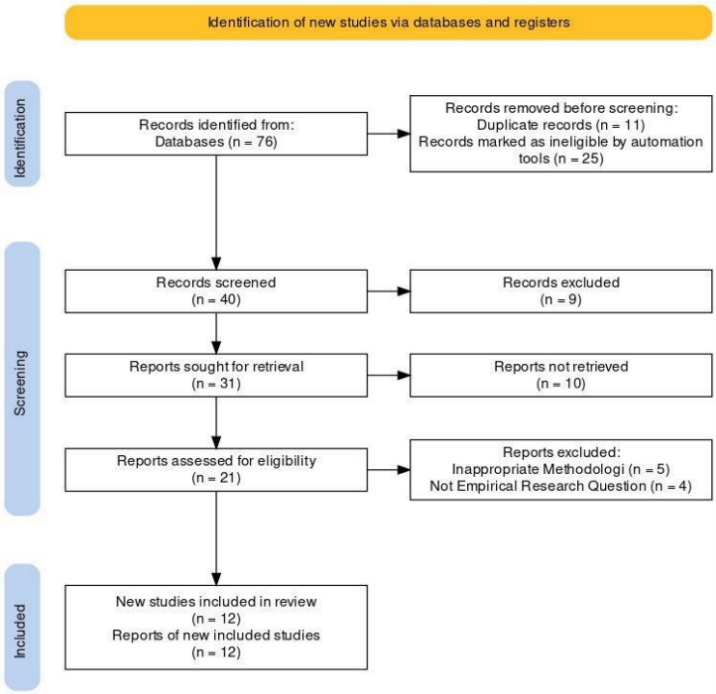

Figure 1. Prism Flow Diagram

Based on the flow chart data above, there are 76 articles that correspond to the general topic of discussion. Then, after filtering, it came back to 40 articles to suit what was needed. Then, based on the content in it, namely about the application of the guided inquiry model which can improve critical thinking skills in science learning, 12 articles were obtained.

Results

The guided inquiry learning model involves students actively in the learning process, allowing them to explore,

investigate and discover concepts independently. This is very important in developing critical thinking skills. In this article we will discuss the effectiveness of the inquiry learning model in improving critical thinking skills. Based on a study of research journals from various online journal sources, 40 journal articles were studied.

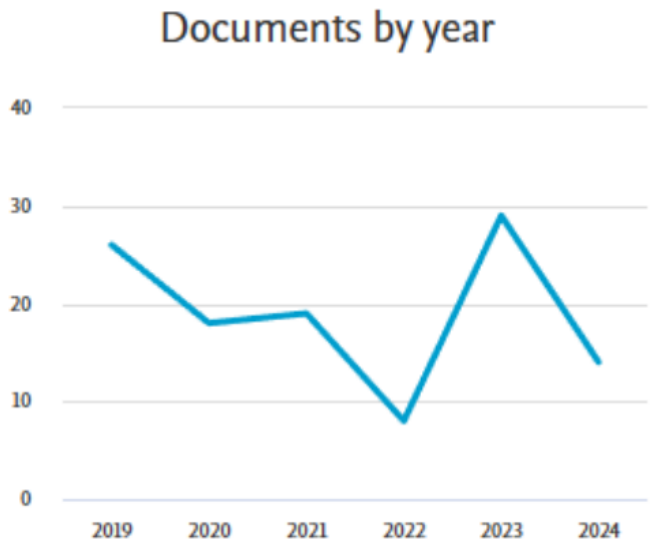

Figure 2. Publication of Research on Inquiry Learning Models on Critical Thinking Abilities for the 2019 – 2024 Period

Based on Figure 2, where the diagram is specific to the fields of physics, astronomy and chemistry, the data obtained in 2019 is the largest journal publication of 11 journals, while in 2024 it is the smallest journal publication of 2 journals. The following is an illustration in the form of a line diagram.

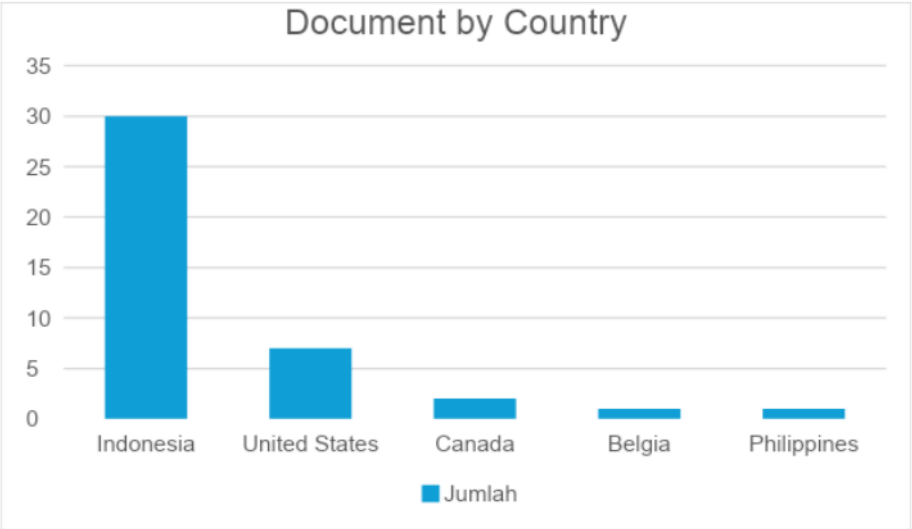

Figure 3. Research Publication Inquiry Learning Model Conceptual Understanding Seen from Country of Publication

The research was conducted to obtain indicators of the guided inquiry learning model which is used as a parameter for students' critical thinking abilities. The results of the line diagram above show that research publications on the guided inquiry learning model to improve students' critical thinking abilities from 2019 to 2024 have decreased each year until 2022 by 4 journals. Then it experienced an increase again in 2023 by 10 journals and finally decreased again in 2024 by 2 journals. The number of guided inquiry learning model journals to improve students' critical thinking skills is based on this, this topic is still worthy of further research.

Based on data obtained in Figure 3, the country that publishes the most journals is 97 journals in Indonesia, while the countries with the lowest publications are China, Colombia, Ethiopia, Finland with 2 journals. The following is an overview in bar chart form. The results of the third analysis can be seen in the image above of 5 research publications on the inquiry learning model for understanding concepts seen from the country of publication. Based on the bar diagram, it can be said that Indonesia dominates the category of countries that publish journals on the inquiry learning model for understanding students' concepts in science learning.

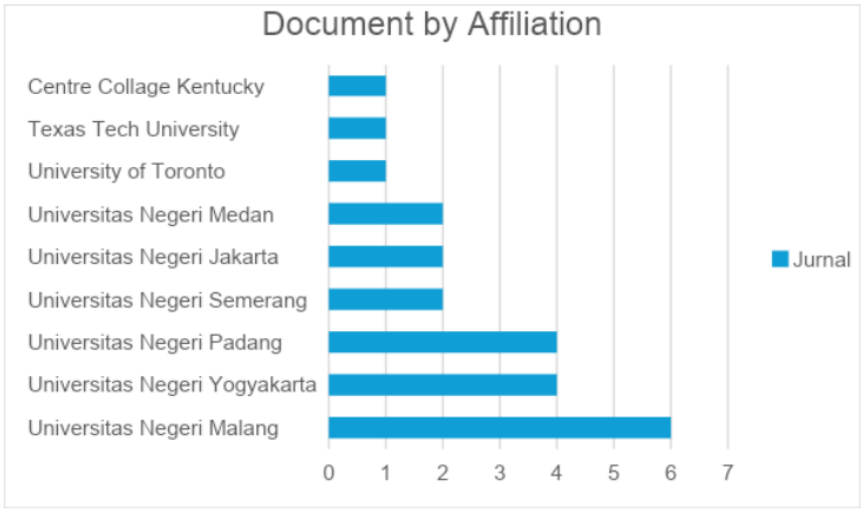

Figure 4. Publication of Research on the Guided Inquiry Learning Model for Critical Thinking Ability seen from the Place of Publication

Based on data in Figure 4 obtained especially in the fields of physics and astronomy and chemistry at Malang State University with 6 journals, then continued with Yogyakarta State University and Padang State University with 4 journals, comedian Semarang State University, Jakarta State University and Medan State University with 2 journals. Then there is the University of Toronto, Texas Tech University, Center Collage Kentucky and University of Iowa with a total of 1 journal. So the results from the diagram above show that the topic of guided inquiry learning models to improve students' critical thinking skills has received the most publications at the State University of Malang in Indonesia compared to other universities.

From the articles studied, there were 12 articles with problematic topics. The research results are listed as follows:

Table 1.

	Title	Learning Model	Research Result
(Putri & Syafriani, 2020)	Analysis Development of Guided Inquiry Based Physics E-Module to Improve Critical Thinking Ability of Students High School	Guided inquirybased e-Module	The implementation of guided inquiry-based physics e-modules is effective in improving high school students' critical thinking skills
(Makmur et al., 2019)	Implementation of Guided Inquiry Learning With Scaffolding Strategy to Increase Critical Thinking Skills Of Biology Students' Based On Lesson Study	Guided Inquiry Learning with Scaffolding Strategy	Improving the critical thinking skills of biology students with an increase from cycle I to cycle II in the application of indicators by around 27.5%, analysis by around 15%, use of data by around 15%, and synthesis by around 25%.
(Aiman et al., 2020)	Process Oriented Guided Inquiry Learning to Increase Student's Critical Thinking Ability on Chemistry Learning at Islamic High School in Cirebon	Guided Inquiry Learning	The implementation of the Process Oriented Guided Inquiry Learning (POGIL) teaching model had a positive effect on students' critical thinking ability. The post-test and N-gain mean values of students' cognitive learning outcomes and critical thinking ability were higher in the classroom with the POGIL model compared to conventional learning.
(R. K. Dewi & Wardani, 2020)	Guided inquiry assisted by edmodo application to improve student critical thinking skills in redox material	Guided Inquiry	Implementing guided inquiry with the support of the Edmodo application enhances students' critical thinking

	Title	Learning Model	Research Result
			skills. The improvement test revealed N-gain scores of 0.6 (medium category) in the control class, and 0.7 (high category) in experimental class 1, and 0.72 (high category) in experimental class 2.
(Susanti, 2020)	Application of the Scientific Approach Using Guided Inquiry to View the Ability of Critical Thinking Students	Guided Inquiry	The scientific approach using guided inquiry in Social Statistics courses showed an average student activity of 80%. Students' critical thinking skills were classified as very good, especially in identifying assumptions and solving problems
(Phonna et al., 2020)	Guided inquiry-based on practicum to improve critical thinking skills on the subject of Newton's law	Guided Inquirybased Practicum	The use of guided inquirybased on practicum significantly improves students' critical thinking skills compared to verification-based practicum
(Putri & Syafriani, 2020)	Analysis development of guided inquiry based physics e-module to improve critical thinking ability of students high school	Guided Inquiry	Guided Inquiry-based emodules can improve high school students' critical thinking skills in understanding physics concepts.
(Kirk et al., 2023)	Critical thinking in primary science through a guided inquiry pedagogy: A semiotic perspective	Guided Inquiry with Semiotic Perspective	The semiotic approach in guided inquiry learning is able to improve students' critical thinking in science through the

	Title	Learning Model	Research Result
			use of multimodal and collaborative representations.
(Kurniawan & Syafriani, 2021)	The validity of e-module based on guided inquiry integrated ethnoscience in high school physics learning to improve students' critical thinking	Guided Inquiry integrated Ethnoscience	The Guided Inquiry-based emodule which is integrated with ethnoscience is valid to use and is able to improve students' critical thinking skills in studying physics in high school.
(Wulandari et al., n.d.)	Validity and practicality of electrolyte and non-electrolyte solution modules posit on guided inquiry with probing prompting technique for grade X in senior high school	Guided Inquiry with Probing Prompting	Guided Inquiry-based electrolyte and nonelectrolyte solution modules with the Probing Prompting technique are valid and practical to use and improve students' critical thinking skills.
(Hakim et al., 2020)	Promoting students' argumentation skill through development science teaching materials based on guided inquiry models	Guided Inquiry	Guided Inquiry-based science teaching materials can improve students' argumentation skills with very good validity and high practicality.

Based on the results of the study, physics is one of the subjects that requires Learning and Innovation Skills, one of which is critical thinking. To develop these skills, a suitable learning model is needed to improve students' critical thinking skills. One learning model that can be applied is the guided inquiry learning model. Based on the results of the articles that have been studied, it can be seen that the application of the LMS-based blended learning model with the guided inquiry learning model is very effective in improving students' critical thinking skills in science learning at the high school level (Khotimah et al., 2023).

The following are several factors that support the effectiveness of this model:

1. Improved Critical Thinking Skills:

The guided inquiry model encourages students to analyze problems, propose hypotheses, and carry out investigations to find solutions (Pursitasari et al., 2020). This process develops analysis and synthesis skills which are the main components of critical thinking skills (Dini et al., 2020). Students are invited to reflect on their learning process, evaluate the information they obtain, and criticize the arguments or solutions they develop. This activity improves critical evaluation and reflection skills (Aljawawdeh, 2024).

2. Application to Various Subjects:

Physics: Research by Putri and Syafriani and Phonna et al. shows that the application of guided inquiry in physics learning can improve students' conceptual understanding and critical thinking skills. Students become more involved in the learning process, which in turn increases their motivation and learning outcomes. The application of the guided inquiry model in physics and chemistry learning shows positive results in improving students' critical thinking skills (Isnawati et al., 2020). For example, in the research of Phonna et al. (2020), the increase in students' critical thinking skills in the experimental class was much higher compared to the control class.

Chemistry: Kisworo and Gusman show that the POGIL model, which is a form of guided inquiry, is effective in learning chemistry. This model not only improves critical thinking skills but also students' cognitive learning outcomes (Saputra et al., 2023).

3. Research Methodology

These studies generally use experimental or quasi-experimental designs with control groups to measure the effectiveness of the learning model. The instruments used include critical thinking skills tests, observations, and interviews (Wartono et al., 2018). Data were analyzed using descriptive and inferential statistics to ensure the validity and reliability of the findings (S. K. Dewi & Sudaryanto, 2020).

4. Consistent Results

Results from various studies show consistent improvements in the critical thinking skills of students who learn with the guided inquiry model compared to conventional learning models (Thacker, 2023). This shows that the guided inquiry model is not only effective but also reliable in various learning contexts (Aristiadi, 2019).

One model that can be used to familiarize students with critical thinking skills in the classroom is the guided inquiry learning model (Wartono et al., 2018). This is in accordance with research which states that the application of the guided inquiry learning model can improve students' critical thinking skills and scientific attitudes in physics learning (Parwati et all., 2020). The main aim of the guided inquiry model is to develop

thinking skills, especially critical thinking, as well as to develop intellectual and problem-solving skills (Turnip et all., 2016). The following is the relationship between the guided inquiry model and indicators of critical thinking abilities:

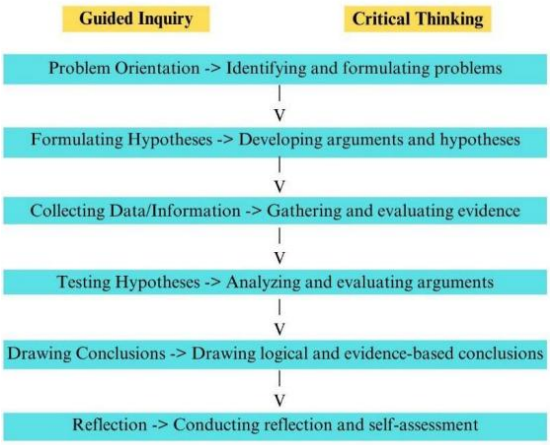

Figure 5. The Relationship Between Guided Inquiry Syntax and Indicators of Critical Thinking Abilities

Based on the picture, the relationship between the syntax of the guided inquiry learning model and the critical thinking indicators is clearly visible. So the first indicator of critical thinking ability is determining relevant problems, then this is related to the first step in guided inquiry learning, namely identifying the problem to be solved. At this stage, students are trained to understand the problem in depth, ask critical questions, and identify important aspects of the problem.

Then the next indicator is collecting and assessing relevant information. This is related to the second syntax where students collect relevant data and information to understand the problem further. This process involves activities such as experimentation, observation, and searching for information from various sources. Students are trained to sort valid and relevant information. Then the next indicator is developing a logical hypothesis based on the data collected related to syntax, that is, after collecting the data, students are invited to develop a temporary hypothesis or conjecture that can explain the phenomenon being studied. This stage encourages students to think logically and analytically. Then the next indicator is conducting experiments or testing to validate the hypothesis. Which is related to the next syntax, namely carrying out experiments or tests to test the hypothesis that has been created.

They are trained to think systematically, plan experiments and analyze the results obtained. Next, the next indicator is analyzing data critically to draw logical conclusions related to the student's syntax for analyzing data obtained from experiments or testing. This analysis process involves critical thinking to evaluate the accuracy of the data, look for patterns, and draw conclusions based on existing evidence. Lastly, reflection and self-assessment are related to the final syntax, namely evaluating the inquiry process by identifying strengths and weaknesses and formulating improvements to make it better. Therefore, the syntax of this guided inquiry learning model is closely related to critical thinking indicators.

Guided inquiry is a learning model designed to train students to investigate problems and solve them based on facts (Parwati et all, 2020). This guided inquiry learning model is very suitable to be applied to science learning and also in the 21st century because it meets the demands of competencies, one of which is critical thinking. The ability to think critically does not come naturally to students, but requires a habituation process through classroom learning activities (Annisa et al., 2018). So based on the literature study that has been carried out, this guided inquiry learning model is very effective in improving students' critical thinking abilities.

Conclusion

The guided inquiry learning model has proven to be effective in improving students' critical thinking skills. This model actively involves students in the learning process, encouraging them to analyze, investigate and evaluate information critically. The research that has been conducted shows consistent results in improving critical thinking skills, both in learning physics, chemistry and mathematics. Implementation of this model can be an effective strategy to improve the quality of education and prepare students with critical thinking skills needed in real life.

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The Effect of Mathematical Curricular Complexity on College Major Stratification

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Abstract: Among the plethora of plausible factors used to explain students' preferences towards certain college majors lies the individual undergraduate student's intrinsic discipline-related mathematical aptitude in tandem with their academic tenacity toward stepwise mastery of mathematical concepts as well as their overall quantitative reasoning ability. Herein, we investigate the hypothetical non-linear relationship between the undergraduate college major stratification currently observed within the United States of America solely as a function of requisite mathematical curricular complexity calculated *via* curricular analytics techniques, a graph theory framework for quantifying curricular tortuosity in the form of academic prerequisites as a quantitative measurement of subject matter entanglements. Beginning with ancillary prerequisites within each eight-semester major course sequence from the university academic catalog, impacts of the curricular framework for a wide array of specific academic majors and major discipline areas ranging across the entire university landscape were regressed with undergraduate graduation data collected over the last half century within the United States National Center for Education Statistics' (NCES) Integrated Postsecondary Education Data System (IPEDS). The role of requisite academic mastery of increasingly complex and cumulative mathematical subject matter was evaluated through a novel variable entitled the mathematical curricular complexity of discipline-specific mathematics course sequence progression requirements. Mathematical curricular complexity was tested as a statistical predictor of both current and historical United States undergraduate baccalaureate degree data and was shown to consistently produce a statistically significant coefficient of determination for the continuously differentiable function established over the academic breadth of the entire university. A nearly exact multiplicative inverse (reciprocal) relationship was observed between the mathematical curricular complexity

and the number of U.S. college graduates stratified by major.

Keywords: Curricular Analytics, Mathematical Curricular Complexity, College Major

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Introduction

Undergraduate major programs within the United States routinely encompass eight to ten required lecture courses along with their *co*-requisite laboratory courses as well as ancillary (cognate) supporting courses. According to the United States National Education Statistics' (NCES) Integrated Postsecondary Data System (IPEDS), the number of U.S. undergraduate students graduating with their bachelor's degrees roughly doubled from close to one million in 1970 to nearly two million in 2020 (National Center for Education Statistics, 2021). Although hundreds of majors remain available to U.S. college students, not all of them remain equal in their popularity. For example, during the 1970-2020 time period the number of physical sciences (primarily chemistry and physics) and mathematics graduates remained essentially constant while the number of bachelor's degree engineering graduates grew proportionately to the number of overall college graduates (National Center for Education Statistics, 2021). Nevertheless, the number of U.S. undergraduate students graduating with health-related degrees grew at six times the growth rate of the overall bachelor's degree graduates (National Center for Education Statistics, 2021). Meanwhile, the U.S. student scores in mathematics for both primary and secondary schools have continued to drop to their lowest levels in over five decades due primarily to a lack of rigor and accountability (National Assessment Governing Board, 2025). Student mathematics scores of fifteen-year-old children within the United States were relatively low on the world-wide scale at thirty fourth (34^{th}) globally (OECD Programme for International Student Assessment, 2025) compared to gross domestic product (market value of all final goods and services) rankings by country wherein the United States of America remains first (International Monetary Fund, 2025).

U.S. college students preliminarily state a preferred major of seemingly free will choice upon initially applying to a university and matriculating to their first year. Nevertheless, a U.S. undergraduate student conventionally formally declares a major during their second year of college. In general, U.S. students must ultimately choose between pursuing either a non-technical (humanities, arts, or social sciences) major, a business-oriented major, or a technical major including science, engineering, or mathematics. In addition, students can elect to pursue a professional development major such as nursing, construction science, or marine transportation leading to internship, bachelor's degree, and ofttimes professional licensure upon graduation. U.S. students are inundated with a plethora of prospects concerning majors wherein each individual must relate predictions concerning labor statistics with their own desires and abilities. Internet, broadcast, and print media directed toward prospective

U.S. college students and their parents has increasingly focused on monetary return on investment (ROI) strategy relating the choice of a college major to a purely economical decision.

Econometric Analyses of College Major Choice

A plethora of factors have been previously considered for how a U.S. student decides to initially elect and subsequently follow a particular college major pathway towards graduation. Economists have modeled the choice of a college major as a purely pragmatic financial move by comparing the monetary returns for different undergraduate majors with the costs (*i.e.* money, time, and effort) associated with completing each type of undergraduate degree program. An econometrics analysis by Hamermesh and Donald (2008) has firmly linked large differences in prospective earnings with the student's choice of college major. Montmarquette *et al.* (2002) have concluded that the impact of a student's expected professional earnings plays an absolutely central role in their choice of college major. Rumberger and Thomas (1993) have also correlated a student's choice of major with expected monetary income along with the effects of institutional quality and the individual student's educational performance. Grogger and Eide (1995) reported that a significant portion of the total change in wage premium for entry-level college graduates was ultimately driven by a simple shift toward majors with specific skills linked directly to a relatively high paying career. James *et al.* (1989) imply that while sending your child to a relatively prestigious U.S. Ivy League university initially appears to be a good investment, sending your child to the public university within your own U.S. state in order to major in engineering (with extensive mathematical courses) in combination with a relatively high grade point average could be an even better monetary investment compared to the prestigious Ivy League education. Large earnings differences do, in fact, exist across careers stemming directly from academic baccalaureate majors within the United States. Economists have abundantly analyzed the extent to which students sort into majors as econometricians clearly predict the student is driven toward perceived future financial success.

Differences in student aptitudes have also been found to influence the choice of college major. Turner and Bowen (1999) provide evidence of ability sorting across undergraduate majors *via* the U.S. college admissions Scholastic Aptitude Test (SAT) scores. Paglin and Rufolo (1990) argue that the difference in mathematical ability as garnered from the quantitative (mathematical) portion of standardized exams, such as the Scholastic Aptitude Test (SAT-M) and the Graduate Record Examination (GRE-Q), encompass the primary reason for the difference in both college major choice and ultimate career earnings observed between both college male and female students. A multiplicity of factors has been proposed by econometricians [Arcidiacono *et al.*, 2004, 2012; Hamermesh *et al.*, 2008] in order to explain an individual's preference for certain undergraduate college majors as an intricate balance between the student's intellectual interests, social identity, and their inherent overall intellectual aptitude within a variety of individual academic areas as well as the occupational employment outlook, prospective career motivational prestige (Maslow's hierarchy of needs), and concomitant monetary rewards (*i.e.* return on investment). Neverthless, economists appear to firmly believe that the choice of college major, albeit a combination of free will and ability sorting, is ofttimes predominantly economically driven in a pragmatic sense towards a student's monetary return on investment.

Research Question

What is the influence solely of formal mathematics classroom achievement on the observed distribution of majors in U.S. bachelor's degree graduates? In contrast to the econometricians *multi*-variable analyses centered on return on investment (ROI), herein we consider the stratification of college majors due to only one (1) single variable: achievement and subject mastery within a student's required mathematics courses involving the student's mathematical perseverance. The overarching hypothesis herein encompasses cumulative achievement and subject mastery at increasingly challenging levels of mathematical learning plays a predictive role in continually guiding a U.S. student from kindergarten through the second year of college at which time he/she chooses a specific college major towards earning a bachelor's degree. Within the framework of their training, four (4) critical stages of mathematical learning appear instrumental toward guiding a student towards a particular type of undergraduate major: (1) at the College Algebra/Trigonometry level, (2) at the Calculus I-II level, (3) within the Multivariable Calculus III/Ordinary Differential Equations/Linear Algebra applied sequence as well as (4) within the transition to primarily theoretical mathematics in Discrete Mathematics and Number Theory, and finally to advanced undergraduate mathematics within courses such as Real Analysis, Complex Analysis, and Advanced Numerical Analysis. Furthermore, lacking cumulative mastery of mathematics in primary and secondary school tends to lead a student towards remedial time and effort in college and ultimately to consider alternative choices of major. Analyses herein were made without any regard to potential differences among U.S. colleges or between male and female students.

Grouping of Terms

Hamermesh and Donald (2008) subdivide business majors into two major categories under the headings of hard and soft wherein hard business majors include accounting, actuarial science, business engineering, data processing, finance, and information science and 'soft'' business majors include general business, management, and marketing. Hamermesh and Donald (2008) also group together anthropology, economics, geography, government, psychology and sociology majors. In his dynamic discrete choice econometric modeling, Arcidiacono *et al.* (2004, 2012) grouped the entire university student body into just six (6) broad categories by academic major encompassing science, humanities, engineering, social sciences, economics, and public policy. In contrast, on the order of 1400 college majors are tabulated within the 2019-2020 National Center for Education Statistics' Integrated Postsecondary Data System (National Center for Education Statistics, 2021). In order to narrow the analysis, majors with a substantial number of graduates above a threshold value tended to be selected. Furthermore, in the curricular analytics research herein grouping of majors into somewhat broader categories involving similar mathematical intensity level requirements, such as humanities, arts, social sciences, health, physical science, engineering, and agricultural majors was carefully considered. In the modeling research herein, the humanities, arts, and social sciences were combined into a single category termed HASS while the undergraduate majors within the science, technology, engineering, and mathematics (STEM) category were finely subdivided in order to analyze the effect of requisite mathematical rigor on each academic pathway. We examine the differences among students in a wide variety of individual, specific baccalaureate instructional

programs across the university landscape in order to quantitatively emphasize both the nuances and interconnectedness involved with learning and applying increasingly complex mathematical subject matter.

Method

Curricular Analytics

Curricular Analytics (Heileman *et al.*, 2017, 2018, 2019, 2020; Wigdahl *et al.*, 2014) is a mathematically based graph theory metric for quantifying the complexity of an undergraduate major course flowchart. The curricular analytics complexity is path dependent and was used here *in lieu* of a subjective course difficulty rating system (Gunderson, 2018; Kelesidis, 2021; Mundfrom, 1991). The curriculum consists of a discrete number of courses in which there are defined requisite (*i.e.* prerequisite or corequisite) relationships between courses. A laboratory course which accompanies a lecture course was considered not only complementary but a strict (synchronous) corequisite herein. A curriculum analytics graph is formed by creating a single vertex for each course, along with edges, notated as arrows ($\rightarrow$), directed from either a prerequisite or corequisite course to a required subsequent course within the curriculum. The complexity for any particular course is composed of two components: a blocking factor (A) and a delay factor (B). The blocking factor (A) merely quantifies the extent to which the course of interest blocks the ability to take other required courses within the curriculum. The total blocking factor for the sequence is the arithmetic sum of all individual course blocking factors (A). A higher blocking factor (A) merely indicates that the particular course of interest serves as a gateway to many other curricular courses.

The delay factor (B) for a particular course is defined as the length of the longest path within the corresponding curriculum, which contains the course of interest. We assume herein that the curriculum should be completed in a sequential manner as defined within the university catalog. The ability to successfully navigate relatively long course pathways without delay is critical for undergraduate academic persistence. If a course on the pathway is merely not completed on time, the student will most certainly be hindered, wherein the delay factor (B) metric quantifies this particular effect. The total delay factor equals the sum of all individual course delay factors (B). Path dependent requirements are common among science, engineering, and mathematics majors containing a plethora of both prerequisite courses and corequisite laboratory courses within the knowledge building process. The course blocking factor (A) and delay factor (B) are weighted by their number of academic credits.

The structural complexity (C) attempts to capture the total impact of curricular architectural connectivity upon student progression through requirements. The complexity (C) for the course of interest is equal to the arithmetic sum of its blocking factor (A) and delay factor (B). The overall curricular complexity is the arithmetic sum of the individual course complexities. There is a high correlation between increased curricular complexity, decreased academic persistence, and lower graduation rates (Slim *et al.*, 2021; Wigdahl *et al.*, 2014). Herein, we calculate a novel term, the *mathematical curricular complexity*, as the sum complexity of all individual mathematics courses within the curriculum. The mathematical curricular complexity is indicative of both the breath and depth of integration of formal mathematical concepts throughout the undergraduate major

curriculum.

Archetypical Examples of Undergraduate University Curricula

For the requisite undergraduate curricular examples, we sought an archetypical, strong, U.S. comprehensive undergraduate institution known for its historical academic rigor. Texas A&M University's main campus in College Station, Texas (founded in 1876) was chosen as our source for exemplary curricula herein as a public, land grant, sea grant, and space grant university with relatively high admissions standards. Texas A&M University currently has 77,000 students of whom 60,000 (78%) are undergraduates. Texas A&M University is particularly competitive within its College of Engineering undergraduate programs wherein 23,000 engineering undergraduate students strive to matriculate into their desired program within an entry-to-a-major application process heavily weighted towards their first-year college science and mathematics final course grades at the university.

Texas A&M University's academic programs are accredited by the U.S. Southern Association of Colleges and Schools and all of the Texas A&M University College of Engineering programs are accredited by the U.S. Accreditation Board for Engineering Technology (ABET). High school students admitted to Texas A&M University on average score at or above the 90th percentile on the U.S. college admissions examinations. Texas A&M University holds a U.S. Carnegie R1 Classification as a doctoral university with very high research activity. In 2025 Texas A&M University was ranked as the 143rd best university in the world by Times Higher Education, 171st by U.S. News and World Report in best global universities, and 154th by QS World Rankings of global universities.

Data Mining of Graduation Data

Data on U.S. college graduates is organized by Classification of Instructional Programs (CIP) codes as reported by each higher education institution to the U.S. National Center for Educational Statistics' (NCES) Integrated Postsecondary Education Data System (IPEDS) within their annual Digest of Education Statistics (DOES). The NCES IPEDS has cumulated undergraduate degree data for the years 1969 to present (U.S. Department of Education, 1997). Data was extracted from the Digest of Educational Statistics for a discrete number of academic majors from 1970 to 2020 from their annual academic table of bachelor's, master's, and doctor's degrees conferred by postsecondary institutions, by sex of student and discipline division (NCES DOES Table 318.30) (National Center for Education Statistics, 2021).

A CIP code is a six-digit taxonomic coding scheme of U.S. higher education instructional programs, made up of three (3) groupings of two-digits each, as defined by the U.S. National Center for Education Statistics (NCES). For example, the first two-digits define the most general grouping of related programs, known as the CIP area. For example, all CIP codes which begin with 27 are encompassed within the broad area entitled "Mathematics and Statistics." The four-digit series represents intermediate groupings of programs that have comparable

content and objectives. For example, 27.03 identifies programs in the "Applied Mathematics" field of study. The full six-digit CIP code represents specific instructional programs. For example, 27.0305 is the CIP code for "Financial Mathematics," a program which focuses on the application of mathematics and statistics to the finance industry, including the development, critique, and use of various financial models. CIP code 27.0305 includes instruction in probability theory, statistical analysis, numerical methods, computation and simulation methods, stochastic processes, economics, and financial markets and applications.

The U.S. federal Classification of Instructional Program (CIP) code taxonomy supports the tracking and reporting of program-level enrollments and program completion activity at all U.S. colleges and universities within the annual National Center Education Stastics' Digest of Education Statistics (NCES DOES) publication. Each academic program at U.S. colleges and universities is assigned a CIP code which best describes the program curriculum and its associated baccalaureate degree program. The full six-digit CIP code taxonomy enables a significantly more accurate comparison of programs across academic institutions compared to merely the name of a baccalaureate program as established by each individual higher educational institution, which may hold significant content differences despite possessing the same major heading.

Results

Mathematical Curricular Complexity

In order to quantify the graph theory curricular complexity of an undergraduate major course flowchart, the recommended eight semester course sequence of the particular college major at Texas A&M University was followed. The recommended course sequence was taken directly from the program requirements within the 2024-2025 Texas A&M University undergraduate catalog (Texas A&M University, 2024). In the example shown in Figure 1 below for the Texas A&M University Bachelor of Science in Nuclear Engineering, all forty-four (44) required courses, seventeen (17) major lecture/laboratory courses, departmental advanced electives, and six (6) ancillary mathematics courses were included. The recommended course sequences for each major were translated into a Microsoft Excel® worksheet in comma-separated values (*.csv*) format as shown in Figure 1.

The Microsoft Excel® worksheet was uploaded to the curricularanalytics.org website and the representative curricular analytics complexity graph was produced as shown in Figure 2 below. Within Figure 2, the edges are depicted as arrows ($\rightarrow$) directed from the prerequisite or corequisite course to the subsequent course within the curricula. The complexity value, equal to the arithmetic sum of the blocking factor and delay factor for each course, is shown within the darkened circle show above each course name in Figure 2. The total complexity for each semester, which is equal to the arithmetic sum of all course complexities required in that particular semester, is shown below each column within Figure 2. The mathematical curricular complexity, which was the arithmetic sum of the complexity values for all required mathematics courses within the curriculum, is equal to 150 for the Bachelor of Science degree in Nuclear Engineering at Texas A&M University shown in Figure 2.

Course ID	Course Name	Prefix	Number	Prerequisites	Corequisites	Strict-Corequisites	Credit Hours	Term
1	Gen Chem 1	CHEM	107				3	1
2	GenChem Lab	CHEM	117				1	1
3	Composition	ENGL	104				3	1
4	Engineering Lab 1	ENGR	102				2	1
5	Calculus 1	MATH	151				4	1
6	ARTS 1	ARTS	101				3	1
7	Physics 1 Lab	PHYS	216	4;5		9	2	2
8	Calculus 2	MATH	152	5			4	2
9	Physics 1	PHYS	206	5			3	2
10	Public Speaking	COMM	203				3	2
11	Gen Chem 2	CHEM	120	1			4	2
12	Physics 2 Lab	PHYS	217	7;8;9		17	2	3
13	Calculus 3	MATH	251	8			3	3
14	Statics	MEEN	221	9	13		3	3
15	Princ Nuclear Engr	NUEN	101				1	3
16	Intro Nuclear Engr 1	NUEN	201		13;17		3	3
17	Physics 2	PHYS	207	8;9			3	3
18	Public Speaking	COMM	203				3	3
19	Princ Electr Engr	ECEN	215	13;17			3	4
20	ODE	MATH	308	13			3	4
21	Thermo	MEEN	315	13;14			3	4
22	Mtls Sci	NUEN	265	1;12			3	4
23	Intro Nuclear Engr 2	NUEN	302	16;20			3	4
24	Prof Writing	ENGL	210				3	5
25	Linear Algebra	MATH	309	13;20			3	5
26	Fluid Mech	MEEN	344	20;21			3	5
27	Nuclear Reactor Safety	NUEN	301	23			3	5
28	Radiological Safety	NUEN	309	23			3	5
29	Economic Analysis	ISEN	302	8			2	6
30	Heat Transfer	MEEN	461	26			3	6
31	Radiataion Detection	NUEN	303	28			3	6
32	Nuclear Reactor Analysis	NUEN	304	25;27			3	6
33	Math Numerical Methods	MATH	417	20;25			3	6
34	Nuclear Engin Experiments	NUEN	405	31;32			3	7
35	Nuclar Eng Sys Design	NUEN	406	30;32			3	7
36	Computer Appl in Nuclear Engr	NUEN	430	32;33			3	7
37	ARTS 2	ARTS	102				3	7
38	Fuel Assembly	NUEN	418	32			3	7
39	Design of Nucl Reactors	NUEN	410	30;32;35			4	8
40	Seminar	NUEN	481				1	8
41	ARTS 3	ARTS	103				3	8
42	ARTS 4	ARTS	104				3	8
43	Nuclear Plant System Transients	NUEN	460	21;26;27;29;30;32;35;36			3	8
44	Process Safety Engr	SENG	455				3	8

Figure 1. Recommended eight semester course sequence interconnected by prerequisite and corequisite courses for the Texas A&M University Bachelor of Science in Nuclear Engineering major (NCES Classification of Instructional Programs Code 14.2301) as taken from the 2024-2025 undergraduate university catalog. Microsoft Excel® file in comma-separated values (.csv) format.

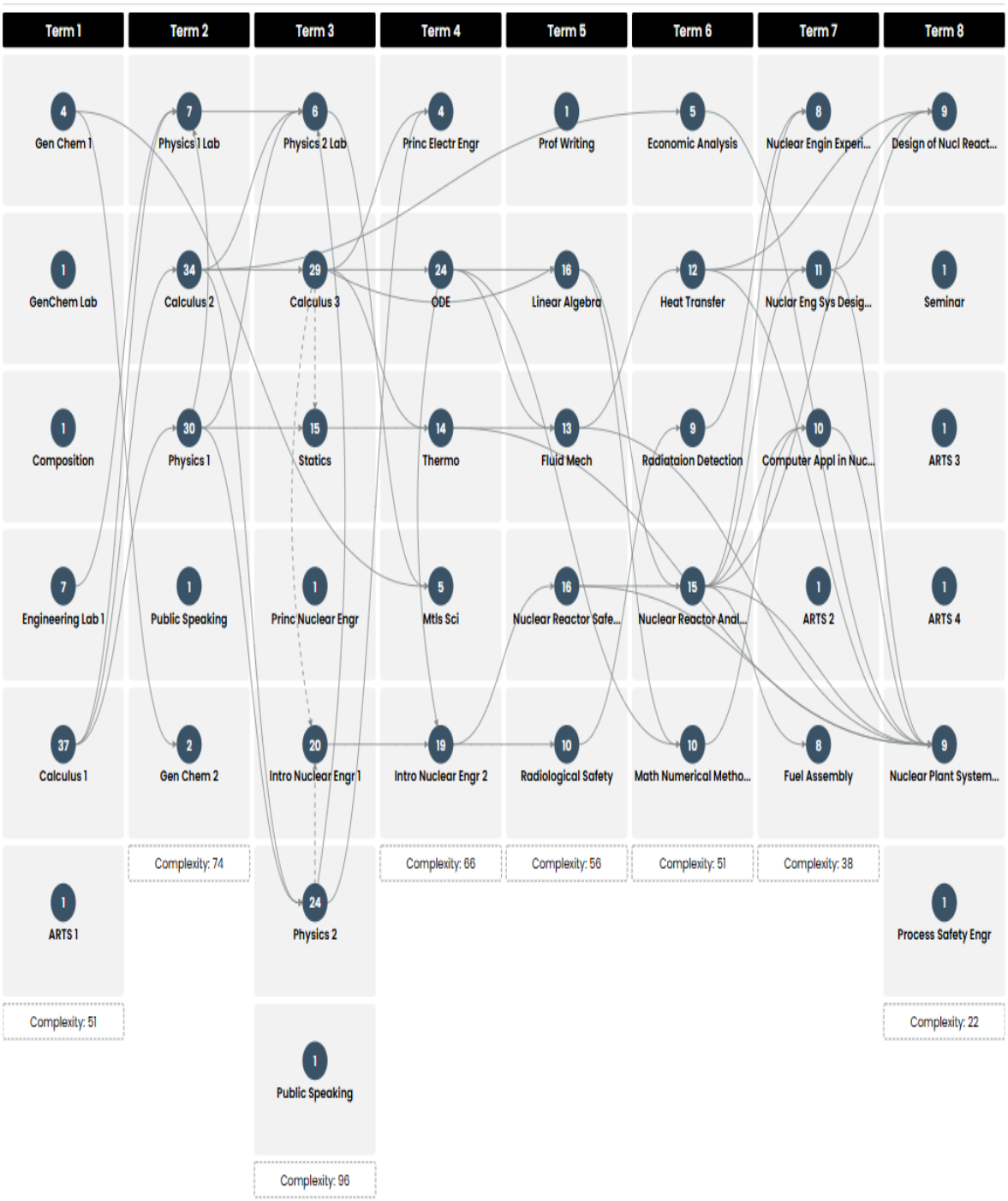

Figure 2. The curricular analytics complexity graph for the Texas A&M University Bachelor of Science in Nuclear Engineering degree program wherein the mathematical curricular complexity is equal to 150. The connectivity edges are shown as arrows (→) from the prerequisite or corequisite course to the subsequent required course within the curriculum.

The interconnectivity of the requisite mathematics courses within the Texas A&M University Bachelor of Science in Nuclear Engineering curriculum are highlighted in Figure 3 below beginning with the Calculus I (Texas A&M University Engineering Mathematics I) course.

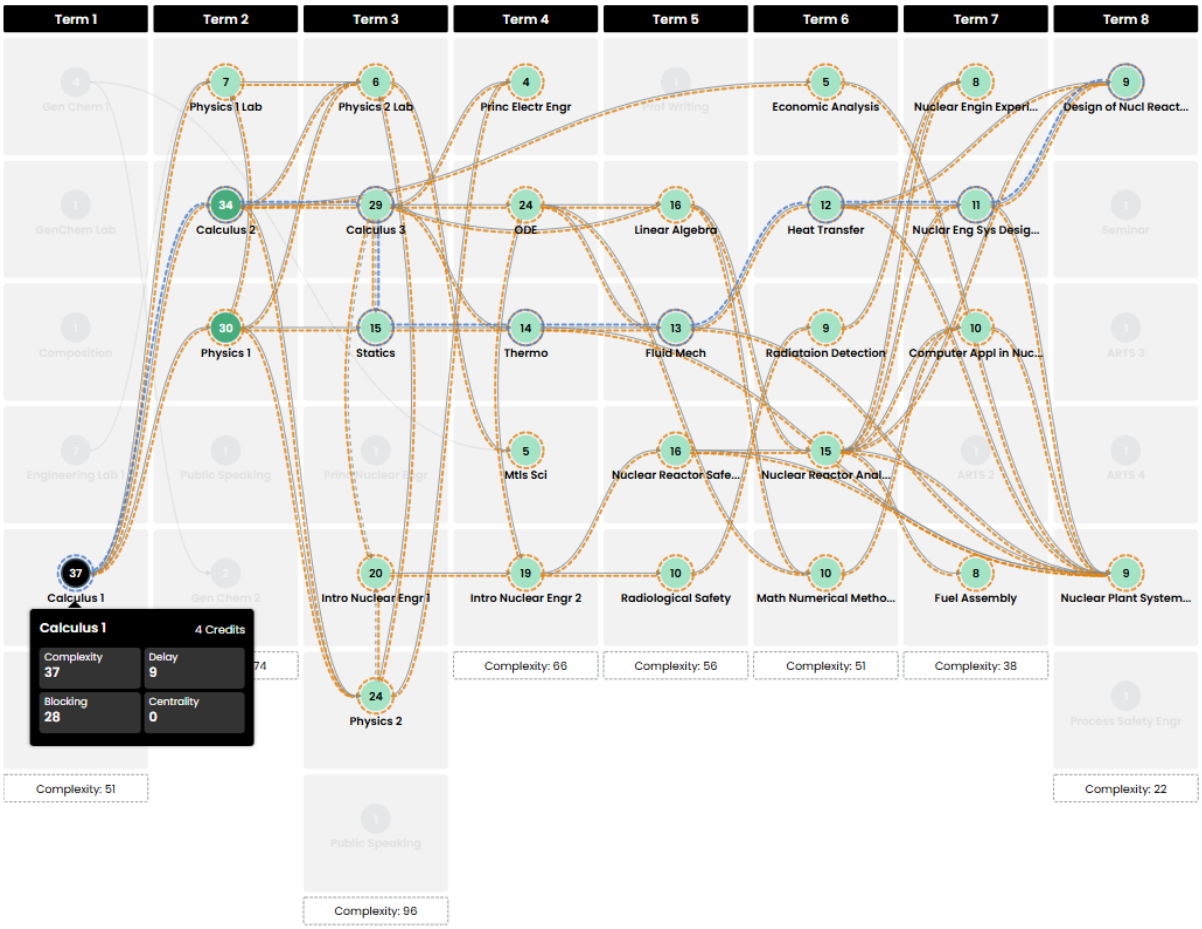

Figure 3. Connectivity of the six (6) required ancillary mathematics courses within the curricular analytics complexity graph for the Texas A&M University Bachelor of Science in Nuclear Engineering degree program. The mathematical curricular complexity for nuclear engineering major was equal to 150.

U.S. Bachelor's Degree Graduation Data

Data mining was accomplished on NCES IPEDS Table 318.30 (National Center for Education Statistics, 2021) for U.S. undergraduate bachelor's degrees as organized by Classification of Instructional Programs (CIP) codes and reported by each U.S. higher education institution. For example, the exact CIP code for nuclear engineering is 14.2301 whereas the CIP code for general physics is 40.0801 from the National Center for Education Statistics (NCES) (National Center for Education Statistics, 2020). NCES has annually cumulated undergraduate degree data for the years 1969 – present as reported within their Integrated Postsecondary Education Data System (IPEDS) (National Center for Education Statistics, 1997). On the order of 1400 bachelor's degree types by specific major or general academic area were accumulated for the 2019-2020 academic year (National Center for Education Statistics, 2021). Within our study, we have extracted IPEDS data for a discrete number (on the order of 40) of academic majors from the years 1977 through 2020 as a data mining effort from chronologically tabulated records. The key to the modeling herein involved deciding how exactly to group the college majors. Less quantitative college major areas were potentially combined while increasingly technical majors in science, engineering, and mathematics were finely subdivided in order to more

precisely observe the effect of mathematical curricular complexity. The most general form of the major (*i.e.* physics, general, 40.0801; chemistry, general, 40.0501) from IPEDS data were routinely utilized herein (National Center for Education Statistics, 2020). A representative set of individual college majors and major areas which were utilized are shown in Table 1 below along with the number of U.S. bachelor's degree graduates in 2019-2020 as reported to NCES IPEDS (National Center for Education Statistics, 2021) and the mathematical curricular complexity from Texas A&M University major programs as calculated using curriculum analytics graph theory techniques.

Table 1. A representative set of individual college majors, their corresponding number of bachelor's degrees granted to U.S. students within that particular field in 2019-2020, and the mathematical curricular complexity calculated for the particular major from graph theory curricular analytics techniques.

College Major	Number of Graduates	Mathematical Curricular Complexity	College Major	Number of Graduates	Mathematical Curricular Complexity
Nuclear Engineering	472	150	Meteorology	719	72
Electrical Engineering	17,299	149	Computer Science	34,208	66
Petroleum Engineering	1,123	147	Chemistry	13,549	46
Aerospace Engineering	5,280	145	Finance	42,161	41
Mechanical Engineering	37,347	141	Industrial Distribution	5,810	39
Physics	7,342	130	Computing	27,438	33
Chemical Engineering	10,537	124	Economics	23,210	31
Mathematics Teacher Education	1,262	124	Biochemistry	9,062	30
Biomedical Engineering	8,110	116	Computer Information Science	23,686	25
Econometrics	10,547	113	Engineering Technology	19,375	22
Statistics	3,294	112	Kinesiology	25,424	18
Mathematics	18,461	112	Architecture	3,595	14

Finance/ Mathematics Double Major	375	111	Biology and Neuroscience	126,590	9
Architectural Engineering	684	109	Agriculture and Natural Resources	62,355	7
Geophysics	93	106	Nursing	148,791	6
Industrial Engineering	5,857	89	Business Management	387,140	2
Finance with Mathematics and Economics	375	89	Humanities, Arts, and Social Sciences	732,492	1
Materials Science	1,620	88			
Computer Engineering	9,567	79			
Civil Engineering	14,871	75			

Herein, we query whether there is a statistical correlation between the mathematical curricular complexity for college majors and the number of U.S. bachelor's degrees granted in that field across the university landscape. Is there, in fact, one single academic variable which predicts the number of U.S. bachelor's degree graduates across the entire university terrain rather than a plethora of weighted economic factors (Arcidiacono *et al.*, 2004, 2012; Hamermesh *et al.*, 2008)?

Statistical Bivariate Correlation and *Non*-Linear Regression

Mathematical curricular complexity for a discrete set of college majors was tested as a statistical predictor of current United States undergraduate baccalaureate degree data as shown in Figure 4.

For 2019-2020 graduation data (Nation Center for Education Statistics, 2021), the mathematical curricular complexity was shown to produce a statistically significant coefficient of determination (R^2) of 0.9789 for the continuously differentiable function established over the academic breadth of the entire university as shown in Figure 4 above. The coefficient of determination (R^2) method is a statistical measure in a regression model which determines the proportion of variance in the dependent or response variable (the number of U.S. bachelor's degree graduates) that can be explained by the independent or explanatory variable (the mathematical curricular complexity herein) and ranges from a value of zero to a value of one indicating a perfect fit. Furthermore, a nearly multiplicative inverse (*i.e.* a reciprocal) relationship ($y = ax^{-k}$ power law exponent, where k = 1.122) was observed from the non-linear power law regression for the number of U.S. bachelor's degree

graduates versus the mathematical curricular complexity. Thus, a single variable, the mathematical curricular complexity, correlated with the stratification of U.S. bachelor's degree graduates in 2019-2020 for college majors ranging across the entire university landscape.

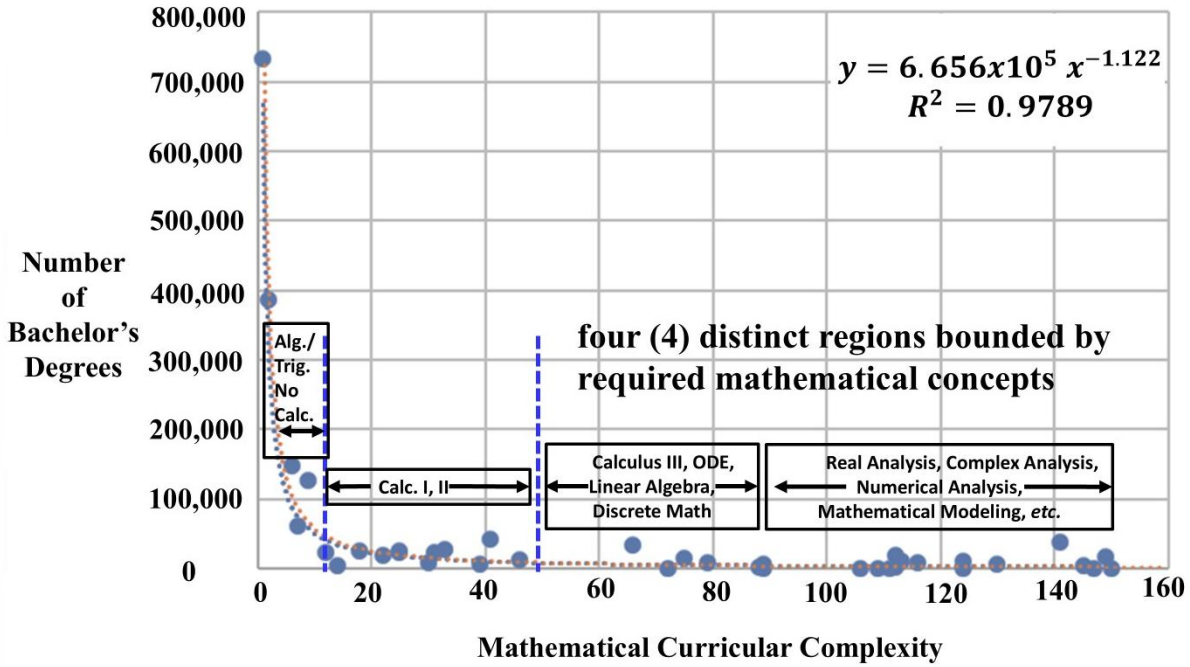

Figure 4. Number of U.S. bachelor's degree graduates by subject in 2019-2020 from NCES IPEDS versus the mathematical curricular complexity calculated using curricular analytics techniques. The best non-linear power law regression fit is shown as the dotted line (---). The non-linear power law type of regression was used to model this particular relationship wherein the response (y) variable was equal to the predictor (x) variable raised to a power as $y = ax^{-k}$, where a is a constant.

Historical Analysis of U.S. Bachelor's Degree Graduate

The mathematical curricular complexity was tested as a statistical predictor of United States undergraduate baccalaureate degree data by subject over fifty years from the years 1970 to 2020 as shown in Table 2 below.

Table 2. Non-linear regression power law ($y = ax^{-k}$) analysis of chronological IPEDS data with the calculated mathematical curricula complexity. The *logarithm of the* number of U.S. Bachelor's degrees by subject was plotted versus the *logarithm of the* mathematical curricular complexity as organized by chronological academic year. A power law model fit ($y = ax^{-k}$) for each academic year was accomplished usign non-linear regression within the Microsoft Excel® program.

Academic Year	Pre-exponential factor (a)	Exponent, k (number of data points)	Correlation coefficient squared (R^2)
1969-1970	1.786×10^5	1.059 (29)	0.6868

1980-1981	4.939×10^5	1.213 (34)	0.7648
1990-1991	5.669×10^5	1.259 (34)	0.6819
2000-2001	7.182×10^5	1.296 (35)	0.7248
2010-2011	4.333×10^5	1.153 (40)	0.8613
2019-2020	6.656×10^5	1.122 (42)	0.9789

A suitabe non-linear power law regression fit was consistently noted over the years 1970 through 2020.

Discussion

Mathematical Curricular Complexity Effects

A significantly wider variety of college majors was available to U.S. students in 2020 (National Center for Education Statistics, 2021) at the end of the fifty year progression depicted in Table 2 compared to the beginning in 1970 as tabulated by NCES IPEDS (National Center for Education Statistics, 1997). Nevertheless, the same non-linear regression power law type fit ($y = ax^{-k}$) was observed to be valid over the five decade (1970-2020) time period as calculated each decade (Table 2) and the exponent (k) was observed to remain effectively constant and very close to a value of unity (one) as shown in Table 2. The non-linear power law regression fit shown for 2019-2020 in Figure 4 and chronologically in Table 2 was indicative of the keen dependency of cumulative mathematics mastery directly on the number of U.S. students finishing college majors with increasing technical content. As our scientific knowledge base expands, a mastery of increasingly complex mathematical techniques and proofs are required. The nearly multiplicative inverse (*i.e.* reciprocal) relationship observed herein in Figure 4 indicates that merely requiring more mathematics for any particular undergraduate major will steeply decrease the number of U.S. bachelor's degree graduates, which is evident over the last half century from the data in Table 2. Hence, the primary and secondary (kindergarten through twelfth grade) mathematical preparation and rigor must substantially increase within the United States in order to concomitantly increase U.S. science, engineering, and mathematics bachelor's degree graduation rates.

In some cases, even though the number of requisite mathematics courses was increased within a particular bachelor's degree curriculum as compared to another major, less mathematical concept application and integration was poignantly observed within curricular semesters 5-8. Hence, a relatively lower calculated value for the curricular mathematical complexity was observed. For example, although the bachelor's degrees in physical sciences (physics and chemistry) require substantial formal mathematics coursework, off times equal to their engineering major counterparts, the integration of required mathematical prerequisite concepts in nuclear, electrical, aerospace, mechanical and petroleum engineering curricula was far greater. The primary application of multivariable calculus, differential equations, and linear algebra lies almost solely in the physical chemistry courses for a Bachelor's degree in Chemistry.

However, the mathematical curricular complexity for a technical major can, in fact, be altered. A strategic three (3) semester applied mathematics sequence aimed specifically at preparing students for the Physical Chemistry I

(thermodynamics) and Physical Chemistry II (quantum mechanics) course sequence was detailed by Neville *et al.* (2018). The course sequence begins with limits, continuity, differentiation, and integration of elementary functions with applications as well as studying conic sections. The middle course within the sequence aimed at applied mathematics specifically for chemistry majors incorporates series and limits, Taylor series, complex variables, first-order and second-order ordinary differential equations, matrices, linear transformations, determinants, and eigenvalues. The final course within the sequence in applied mathematics for chemistry majors incorporates vector fields, partial differentiation, cylindrical and spherical coordinates, multiple integrals, line integrals, the wave and Schrödinger equations, the separation of variables method, inner product spaces, and Fourier series. This three course sequence (Neville *et al.*, 2018) replaces the conventional Calculus I, Calculus II, Calculus III, Ordinary Differential Equations, and Linear Algebra five (5) cognate mathematics course sequence recommended by the American Chemical Society (2015, p. 15) and thereby would significantly decrease the mathematical curricular complexity for a Bachelor's degree in Chemistry *via* ancillary pre-requisite learning objectives tailored specifically for the subsequent mathematically centered major courses in physical chemistry.

Despite the requisite mathematics coursework, a relatively lower mathematical curricular complexity value was observed for the Bachelor of Science in Mathematics compared to many engineering majors at Texas A&M University. Although substantial in magnitude, the undergraduate mathematics course progression required for a Bachelor's degree in Mathematics does not have an expansive tree (hyperbranched) or web-like structure within semesters 5-8 in comparison to the nuclear engineering major depicted in complexity graph form in both Figure 2 and Figure 3. Once a mathematics major progresses past courses in discrete mathematics, linear algebra, and multivariable calculus, the subsequent mathematics courses tend to be somewhat independent of one another despite being purely mathematical in nature. Hence, often far less graph theory edge ($\rightarrow$) connection is drawn between advanced undergraduate mathematics subjects such as combinatorics, number theory, topology, and complex analysis, which would have prospectively strengthened both the blocking factors and delay factors for those courses and concomitantly substantially increased their mathematical curricular complexity values within the Bachelor's degree in Mathematics major curricula. However, due to the lower prerequisite web or tree-like hyperbranching, the Bachelor's degree in mathematics remained ironically relatively low on the mathematical curricular complexity scale for a highly technical major as shown in both Table 1 and Figure 4.

Within the observed power law fit shown in Figure 4, four (4) distinct regions bounded by their requisite mathematical concept mastery were observed. Hence, mastery at four (4) critical stages of mathematical learning appear instrumental toward ultimate success while significantly increasing the technical content of a student's undergraduate major: (1) at the college algebra/trigonometry level, (2) at the calculus I-II level, (3) within the multivariable calculus/ordinary differential equations/linear algebra applied sequence level, as well as (4) at the transition to primarily theoretical mathematics in Discrete Mathematics and Number Theory, and finally to advanced undergraduate mathematics learning in Real Analysis, Complex Analysis, Numerical Analysis, and Mathematical Modeling. Progression in statistics learning is certainly related to mathematics and

vital to fields such as advanced physics and chemistry, computer science, financial mathematics, and quantiatitive economics. Nevertheless, required statistics courses at any level (lower division or upper division) within an undergraduate major were not exclusively counted here in calculating the mathematical curricular complexity.

Positive deviations from the non-linear regression in Figure 4 were observed for both the finance and mechanical engineering majors due to their broad applicability within the U.S. work force as well as their historical popularity among college students. Positive deviation from the power law fit in Figure 4 was also observed for the computer science major based on its relatively recent popularity and exciting applicability within the rapidly expanding information technology and artificial intelligence fields. Positive deviation from the power law fit in Figure 4 was observed for nursing majors based on the recent popularity of this particular major stemming from a substantial increase in U.S. hospital and clinical positions for professionally licensed Bachelors's degree in Nursing (BSN registered nurses) graduates. A positive deviation from non-linear regression was observed for the biology major due directly to its historic role as the archetypical undergraduate major towards U.S. medical school admissions and health science careers.

Conclusion

Mathematical Curricular Complexity

A new variable, the mathematical curricular complexity, was tested as a statistical predictor of both current and historical United States undergraduate baccalaureate degree data by college major. The mathematical curricular complexity was observed to consistently produce a statistically significant coefficient of determination (R^2) for the continuously differentiable function established over the academic breadth of the entire university. Hence, the number of baccalaureate graduates in fields across the university landscape appears to be statistically correlated with one (1) single variable: the mathematical curricular complexity in contrast with the dozens of weighted economic-type variables proposed previously by econometricians (Arcidiacono *et al.*, 2004, 2012; Hamermesh *et al.*, 2008).

Furthermore, the number of graduates appears essentially inversely proportional to the mathematical curricular complexity. The multiplicative inverse (*i.e.* reciprocal) relationship trend observed between the NCES IPEDS recorded number of U.S. undergraduate students graduating in a finite set of close to forty U.S. college majors and the required curricular mathematical complexity appears to be valid historically over the past half century. The key to the modeling accomplished herein involved grouping certain less quantitative college major areas while finely subdividing science, engineering, and mathematical major fields as well as quantitative business in addition to curricula involving forming a double major with mathematics.

In general, an increasingly mathematical single major or double major with mathematics tends to lower the entry-level unemployment rate for graduates and increase the annual salary for professional positions requiring mathematical calculation skills. Ironically, we have used graph theory mathematical techniques herein to

effectively prove consistent student mastery of mathematical concepts throughout the educational experience is absolutely vital. When viewed within a complexity graph such as Figure 2 and Figure 3 hereinabove, each major appears to be an intellectual maze. Within science, engineering, and mathematical fields each particular college major labyrinth appears to be a complicated and irregular network of passages, which is seemingly quite challenging to traverse. However, the gradual knowledge building process involving increasingly complex mathematical problem solving skills catalyzed by mastering prerequisite and corequisite course content allows students to seamlessly wind their way towards graduation and ultimately professional success. However, if mastery of mathematical course content is not attained, traversing the maze of a technical major may seem absolutely insurmountable.

Remediation and Delay Factors

Requisite remedial mathematics causes a rapid increase in the curricular analytics blocking factors and delay factors as well as the concomitant mathematical curricular complexity of each science, mathematics, and engineering major. For example, non-calculus ready engineering students requiring just one (1) single pre-calculus course in graphs, functions, trigonometry linear systems, and vectors (Texas A&M mathematics course entitled Functions, Trigonometry and Linear Systems) adds at least 22% to the mathematical curricular complexity of the Bachelor of Science in Nuclear Engineering degree program at Texas A&M University. Ofttimes this delay and pressure to pass remedial (before Calculus I) mathematics courses in order to matriculate through a curriculum tends to discourage many students seeking science and engineering majors. In addition to increased time to degree, students placing into remedial mathematics courses (*i.e.* non-calculus ready) *via* the initial mathematics placement examination (MPE) at Texas A&M University often incur significantly escalating cumulative tuition, housing costs, textbook costs, university fees, and concomitant student loans compared to their calculus-ready student counterparts in trying to earn technical undergraduate degrees.

Recommendations

Mathematical Curricular Complexity

Potential mathematics remediation underscores the true importance of cumulative mathematics mastery in higher education science, technology, engineering, and mathematics as well as potential signs of a true lack of rigor in current U.S. primary and secondary school mathematics classrooms wherein learning expectations, habits, achievement, and concept mastery are set forth very early within a child's academic progression. A keen emphasis on mastering mathematical concepts early within the educational experience will allow students to choose from the full gamut of college majors as desired.

Using the same logic in modeling as detailed herein, other specific curricular complexity values could be correlated with the number of U.S. Bachelor's degree graduates, such as the chemical curricular complexity encompassing all requisite chemistry courses specific to biology, agricultural, food science, biochemistry,

chemistry, and chemically oriented engineering majors. Although not considered herein, the statistical correlation of mathematical curricular complexity with the number of U.S. bachelor's degree graduates may produce a fascinating comparison for historical (chronological) data when differentiating between male and female college students.

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Ethno Science: Exploring Physics Concept on the "BESEI KAMBE" Traditional Sports in Central Kalimantan

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Abstract: This research investigates the embedded physics concepts within a Dayak Ngaju cultural heritage, "Besei Kambe", a traditional boat race of the Dayak tribe in Central Kalimantan, Indonesia. Besei Kambe, involving four participants divided into two teams rowing in opposite directions, serves as an intriguing case to explore principles such as kinematics, dynamics, and conservation of energy. By examining Besei Kambe within the framework of ethno physics, this study aims to uncover how fundamental physics concepts are intuitively applied in this cultural practice. This article employs a descriptive qualitative method, combining observational analysis, YouTube video recordings, and theoretical physics calculations to identify the relevant physics concepts. The findings reveal several physics concepts within this traditional sport of Besei Kambe, including Newton's Third Law: action and reaction, net force, Newton's Second Law of Motion, frictional force, Archimedes' principle: buoyant force, work and energy, and momentum and impulse involved in Besei Kambe. The results reveal the application of sophisticated physics principles, demonstrating how traditional practices can embody complex scientific knowledge. This research not only highlights the cultural significance of Besei Kambe but also emphasizes its educational potential as a means of teaching and understanding physics in a real-world context. It can also foster collaboration between teachers, researchers, and cultural practitioners in developing contextualized and locally-based teaching materials. This research advocates for integrating cultural heritage into the educational framework to enrich learning experiences and promote greater appreciation for local cultural preservation efforts.

Keywords: Ethno Science, Physics Concept, Local Culture, Besei Kambe

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Introduction

Physics education should not be limited to memorizing formulas or performing calculations, but must encompass a deeper understanding of the concepts that explain natural phenomena. As a science, physics aims to uncover the fundamental principles underlying these phenomena (Taurusi et al., 2024). However, many students in Indonesia still consider physics to be one of the most difficult subjects. This is largely due to the low interest students have in learning physics (Amalissholeh et al., 2023), which makes it harder for them to understand physics concepts and formulas (Sampe Daun et al., 2020). One of the contributing factors is the heavy reliance on traditional teaching methods, which often tend to be monotonous (Winarti et al., 2021). These methods usually offer general examples or examples that are already familiar to the students, without relating them to the context of their environment, even though such events are related to physics (Mardana et al., 2022). Therefore, a more targeted and relevant approach is needed. One promising solution is to integrate physics education with students' everyday experiences and local culture (Yuenyong & Yuenyong, 2012).

Contextual and relevant physics education is essential for building cultural identity and increasing student engagement in the learning process. Culture-based physics learning enables students to understand the material in a more contextual way (Astuti et al., 2021). By incorporating local cultural elements into the science curriculum, educators can create more meaningful and relevant learning experiences, which in turn strengthen students' understanding of scientific concepts (Sotero et al., 2020). However, in reality, many schools in Indonesia still apply teaching approaches that are disconnected from the local cultural context. Science education often relies solely on textbooks that discuss abstract theories without considering local potential that could strengthen students' understanding of scientific concepts (Atmojo et al., 2019; Sotero et al., 2020). As a result, students often have a weak connection between scientific knowledge and their daily lives.

Ideally, physics education could integrate local cultural diversity to preserve culture and appreciate existing local knowledge. Learning becomes more meaningful when linked to daily life or the local wisdom of the community (Dani et al., 2022). Culture-based science learning can enhance scientific literacy and students' understanding of scientific concepts in a way that is more contextual and relevant to their daily lives (Suastra, 2010; Atmojo, 2012; Perwitasari et al., 2017; Nadhifatuzzahro & Suliyanah, 2019). However, in practice, the physics curriculum in Indonesia remains homogeneous and does not sufficiently accommodate the richness of local culture. Previous studies show that the integration of culture in physics education is often limited to a narrow context and is not well-integrated into everyday learning processes (Kun, 2013; Rochman & Nasrudin, 2017). Research by Fauzi et al. (2022) reveals that despite its great potential, the integration of local wisdom in science and physics education is still limited, even though it could improve students' learning outcomes. Additionally, Suastra (2005) highlights that local cultural values are often overlooked in science and physics education in schools, indicating a lack of integration of local culture into the educational process. In fact, local wisdom, which is rich in cultural values, must be preserved and maintained for future generations (Suwandani et

al., 2022). Therefore, cultural preservation can be achieved by integrating Indonesian culture into education.

The integration of local wisdom, culture, and traditions into physics education is crucial (Ali & Aprilia, 2024). This is because physics often deals with abstract concepts and complex equations, which can be better understood when linked to local culture (Mavhunga & Kibirge, 2018). Ethnoscience-based learning aims to introduce students to facts that have developed in society, which are then connected to learning materials (Septiaahmad et al., 2020). Ethnoscience-integrated learning creates a contextual learning experience (Dani et al., 2023), which enhances students' understanding of the material being studied. According to Putri et al. (2022), integrating local culture into science learning (ethnoscience) leads to better learning outcomes compared to conventional methods. Suastra et al. (2017) show that through physics education based on Balinese local wisdom, educators can also develop students' positive character traits in secondary schools, such as religiosity, honesty, responsibility, curiosity, and environmental awareness. Additionally, integrating physics education with local culture can improve students' skills in analyzing, interpreting (Wati et al., 2020), and understanding physics materials (Elvianasti et al., 2023). Therefore, it is crucial for teachers to connect physics concepts with local culture that is familiar to students' daily lives or habits (Hasan et al., 2024).

Other studies show that integrating local wisdom, culture, and traditions into physics education (ethnoscience) has a positive impact on the physics learning process. Some of the benefits include improving students' critical thinking skills (Widayanti et al., 2022; Asra & Akmal, 2021), enhancing student creativity (Widayanti et al., 2022; Haspen et al., 2021), influencing the character of patriotism (Maryam et al., 2022), and increasing student learning motivation (Asra et al., 2021; Maryam et al., 2022). Furthermore, ethnoscience-based learning can improve students' understanding of physics concepts (Dani et al., 2022) and positively impact their physics learning outcomes (Ningtyas & Setiawan, 2023). Empowering local wisdom by teachers can create a learning environment that is relevant, meaningful, and inspires pride in students' local culture (Umamah & Andi, 2023). According to Selamat & Priyanka (2023), by integrating ethnoscience into science learning, students experience more relevant and meaningful learning, reducing barriers to learning, and enhancing their curiosity and active participation in the subject. Ethnoscience-based physics learning also offers additional benefits, such as creating creative learning media, engaging teaching tools, and teaching models that can be linked to ethnoscience itself (Kasim et al., 2025). Therefore, ethnoscience-based physics education can create more meaningful and relevant learning experiences related to students' daily lives and enhance their skills.

Indonesia, as a vast archipelago with thousands of islands and diverse ethnic groups, possesses a rich cultural heritage, each with unique characteristics that distinguish it from other countries (Agustin et al., 2020; Kasim et al., 2025). Indonesia is known for its abundant natural beauty, which generates various habits, cultures, customs, cuisine, arts, folklore, games, methods of creation, and ways of interacting with nature, all of which contribute to the uniqueness of each region. This cultural diversity is the wealth and pride of Indonesia, which must be preserved (Asra & Akmal, 2021). From traditional customs and ceremonies to arts, music, language, and cuisine, every culture in Indonesia offers something different and intriguing. Many local cultures have the potential to be linked with physics, one of which is the traditional sport "Besei Kambe" originating from the

Dayak people of Central Kalimantan, Indonesia. This traditional sport involves four participants divided into two teams to row a boat in opposite directions, testing physical strength, teamwork, and force dynamics, making it an ideal subject for study in the context of ethnoscience. Upon deeper exploration, Besei Kambe contains many physics concepts that can be used as a source for more relevant and contextual physics learning.

Integrating physics education with cultural traditions offers a new perspective that enriches our understanding of the culture of Central Kalimantan while also demonstrating how scientific principles are embedded in the everyday lives of traditional communities. This research presents a new approach by integrating the local culture of Besei Kambe into physics learning as a concrete example of applying ethnoscience. Compared to previous studies that have examined ethnoscience in various cultures, such as the use of traditional games in physics teaching in Africa (Okere & Keraro, 2012), the exploration of physics concepts in the "Fahombo" tradition of the Nias tribe (Pratiwi & Kuswanto, 2024), or research on physics in the context of Maori culture in New Zealand (Bishop, 2003), this study offers a unique perspective with a focus on the Dayak culture of Central Kalimantan and the traditional sport of Besei Kambe. This research aims to identify physics concepts within local culture that can be used by teachers as a source for more diverse and relevant physics learning materials.

Method

This study uses a descriptive qualitative method. The aim of this research is to explore and clarify the existence of a phenomenon occurring in society (Moleong, 2018; Naba et al., 2024; Pratiwi & Kuswanto, 2024). The technique employed combines observational analysis of YouTube video recordings about the traditional sport of Besei Kambe with theoretical physics calculations to identify relevant physics concepts. The collected data is then analyzed through three stages: first, reducing the data by correlating the video identifications with the appropriate physics concepts; second, presenting the data in a descriptive textual format; and third, drawing conclusions. By utilizing a descriptive qualitative method, this study provides a deeper and more detailed understanding of the "Besei Kambe" tradition and how its related physics concepts can serve as a more diverse and relevant learning resource.

Results and Discussion

“Besei Kambe”

Besei Kambe, a unique cultural heritage of the Dayak Ngaju people, is a traditional rowing competition. The name "Besei Kambe" carries deep meaning, referring to "oar" and "ancestral spirits." For the Dayak community, this competition is not just a sport but also a ritual to honor their ancestors. In the traditional sport of Besei Kambe, participants, consisting of four members, are divided into two teams, each consisting of two members, as shown in Figure 1. Both teams are in the same boat and sit back-to-back, with one team positioned at the front of the boat and the other at the back. Each team must compete with all their might to row the boat in opposite directions. The team that first crosses the finish line determined by the judges is declared the winner. This competition aims to introduce and preserve traditional sports from Central Kalimantan, which originate

from ancient folklore about spirits rowing against each other. However, when viewed from a physics perspective, several physics concepts can be applied.

Figure 1. A Traditional Sport "Besei Kambe"
(Figure taken by Purba Andika in https://www.indonesiakini.go.id)

The results of the physics concept analysis found in the traditional sport "*Besei Kambe*" are presented in Table 1 below.

Table 1. Analysis Physics Concepts in *Besei Kambe*

Physics concepts	**Concept Explanation**
Newton's Third Law: Action and Reaction	In rowing a boat, the oars exert a force on the water, propelling it backward. In accordance with Newton's Third Law, the water exerts an equal and opposite force on the oars, causing the boat to move forward.
Net Force	If two people row a boat in opposite directions, the forces they exert will counteract each other. The boat will move in the direction of the rower exerting the greater force, as the net force acting on the boat will be in that direction.
Newton's Second Law of Motion	In the sport of Besei Kambe, each player exerts a force by rowing the boat. This force is directed backward, attempting to push the boat in the opposite direction of the rowing. The force applied by each team (F) will result in an acceleration (a) of the boat, depending on the mass (m) of the boat and its passengers. The team that applies a greater force will generate a larger acceleration, causing the boat to move further in their direction.
Frictional Force	Friction between the water and the boat's hull, as well as between the oars and the water, will impede the boat's movement. The greater the friction, the more effort is required to move the boat.

Archimedes' Principle: Buoyant Force	A boat can float on the surface of the water because it experiences an upward buoyant force from the water, which is equal to the weight of the water displaced by the boat. This buoyant force is a result of the pressure difference between the bottom and top of the submerged portion of the boat. The greater pressure at the bottom pushes upwards, counteracting the downward force of gravity.
Work and Energy	The act of rowing involves applying a force over a distance, which is defined as work. The chemical energy from the food we eat is converted into mechanical energy, which is then transferred to the boat through the oars. This transfer of energy results in an increase in the boat's kinetic energy, causing it to move.
Momentum and Impulse	When the boat is moving, it has momentum. Momentum is the product of the boat's mass and its velocity. Impulse is the change in momentum of an object that occurs due to a force applied over a short period of time. In the traditional sport of Besei Kambe, when the oar pushes the water backward (action), the water exerts a reactive force forward (reaction) on the boat. This force acts over a short time interval (Δt), generating an impulse that changes the boat's momentum, causing the boat to move forward.

Physics Concepts on "*Besei Kambe*"

1. Newton's Third Law: Action and Reaction

Newton's Third Law states that "whenever one object exerts a force on a second object, the second object exerts an equal force in the opposite direction on the first." This law is sometimes paraphrased as "to every action there is an equal and opposite reaction" (Giancoli, 2016). The essence of Newton's Third Law is the principle of action and reaction. According to this law, every action force is always met with a reaction force of equal magnitude but in the opposite direction. For example (Figure 2), when a person rows a boat, the oar pushes against the water in a backward direction. This is the action force, where the oar applies a force on the water. According to Newton's Third Law, the water exerts an equal and opposite force on the oar, which is directed forward. This reaction force pushes the boat in the forward direction, causing it to move. Thus, the action is the force of the oar pushing water backward, and the reaction is the force of the water pushing the boat forward. The boat's motion is the result of the reaction force from the water.

Figure 2. Illustration the Action and Reaction Forces on a Boat Being Rowed

Newton's Third Law can be formulated as follows.

$$\vec{F}_{action} = -\vec{F}_{reaction}$$

2.Net Force

If an object is at rest, a force is required to initiate its movement—i.e., a force is needed to accelerate the object from zero velocity to a non-zero velocity (Giancoli, 2016). Force is a vector quantity and thus has both magnitude and direction. Therefore, if two or more forces act on an object, we can find the net force (or resultant force) by adding them as vectors (Halliday et al., 2014).

In the case of the traditional sport of Besei Kambe being explored, the boat rowed in the opposite direction will generate a force in the opposite direction. A boat rowed to the right will generate a force to the right, causing the boat to move to the right. Conversely, a boat rowed to the left will generate a force to the left, pushing the boat to the left. See the illustration in Figure 3.

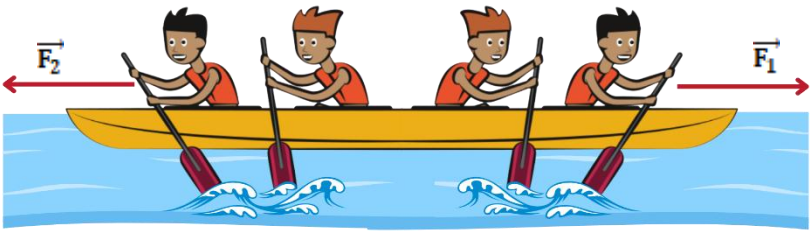

Figure 3. Illustration of The Direction of the Force Vectors $\overrightarrow{F_1}$ and $\overrightarrow{F_2}$ on the Besei Kambe

In Figure 3, the first arrow is labeled $\overrightarrow{F_1}$ to represent the force directed to the right. Then, the second arrow is labeled $\overrightarrow{F_2}$ to represent the force directed to the left. The force vectors $\overrightarrow{F_1}$ and $\overrightarrow{F_2}$ are parallel. The resultant force vector of these two forces is formulated by the equation.

$$\overrightarrow{F_{net}} = \overrightarrow{F_1} + \overrightarrow{F_2}$$

$\overrightarrow{F_{net}}$ is the resultant force vector. The direction of this resultant vector will depend on the magnitudes of the forces $\mathbf{F_1}$ and $\mathbf{F_2}$. If the force $\mathbf{F_1}$ is greater than the force $\mathbf{F_2}$, then the direction of the resultant vector will point in the direction of $\mathbf{F_1}$. Conversely, if the force $\mathbf{F_2}$ is greater than the force $\mathbf{F_1}$, the direction of the resultant vector will point in the direction of $\mathbf{F_2}$.

3. Newton's Second Law of Motion

In the sport of Besei Kambe, each player exerts a force by rowing the boat. This force is directed backward, attempting to push the boat in the opposite direction of the rowing. The force applied will result in an acceleration of the boat according to Newton's First Law, which states, "If no net force is acting on an object at

rest, the object remains at rest; or if the object is moving, it continues moving with constant speed in a straight line" (Giancoli, 2016). However, because there is a net force from each team pushing against each other, the boat will move toward the team applying the greater force. The net force applied to the boat can increase its velocity. Alternatively, if the net force is in the opposite direction of the boat's motion, that force will decrease the boat's velocity. If the net force acts horizontally on a moving boat, the direction of the boat's velocity will change. This change in the direction of velocity is also an acceleration. Therefore, the net force acting horizontally on the boat also causes acceleration. In general, we can say that the net force causes acceleration.

Newton's Second Law also applies here. The force exerted by each team (F) will result in an acceleration (a) on the boat, depending on the mass (m) of the boat and its passengers. The team applying a greater force will generate a greater acceleration, causing the boat to move further in their direction. Newton's second law states, "The acceleration of an object is directly proportional to the net force acting on it, and inversely proportional to the object's mass. The direction of the acceleration is in the direction of the net force acting on the object," and it is formulated in the equation (Giancoli, 2016):

$$\vec{\mathbf{a}} = \frac{\sum \vec{\mathbf{F}}}{m}$$

where $\vec{\mathbf{a}}$ stands for acceleration, m for the mass, and $\sum \vec{\mathbf{F}}$ for the net force on the object.

4. Frictional Force

In the traditional sport of Besei Kambe, the activity of rowing the boat to achieve a certain speed requires a force from the hands to balance the frictional force. Friction is the force that arises when two surfaces come into contact and move relative to each other. This force always acts in the opposite direction of the object's motion and works parallel to the surface in contact (Halliday et al., 2014). Friction can be divided into two main types: 1) Static Friction: The force that acts on an object when it is at rest and tends to resist changes in its position, and 2) Kinetic Friction: The force that acts on an object when it is in motion.

Figure 4. Illustration of Frictional Force on the Besei Kambe Boat

Friction is influenced by the properties of the surfaces in contact, such as surface roughness, and the normal force acting on the object. When the boat moves through the water, the hull experiences friction due to the water. This friction is known as fluid friction or drag force (White, 2011). This force arises due to the interaction

between the boat's hull surface and the water molecules. The frictional force of the water on the boat's hull can affect the boat's speed and efficiency (see Figure 4).

When the boat moves forward, the water exerts a frictional force opposite to the direction of the boat's motion. This force can reduce the boat's speed and requires greater effort from the pushing force of the boat's oar to maintain the desired speed.

5. Archimedes' Principle: Buoyant Force

When a boat is partially or fully submerged in a fluid, the boat will experience an upward buoyant force $\vec{F_B}$ exerted by the fluid (see Figure 5).

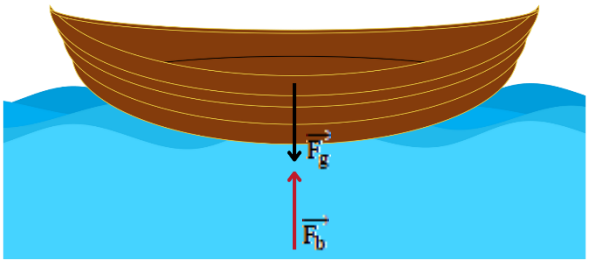

Figure 5. Illustration of a Boat Floating on the Water Surface

This buoyant force arises because the pressure in a fluid increases with depth (Giancoli, 2016). As a result, the upward pressure on the submerged bottom surface of the boat is greater than the downward pressure on its upper surface. To understand this phenomenon, consider a cylinder with a height Δh, where the top and bottom surfaces have an area A, and the cylinder is fully submerged in a fluid with density ρ_F, as shown in Figure 6.

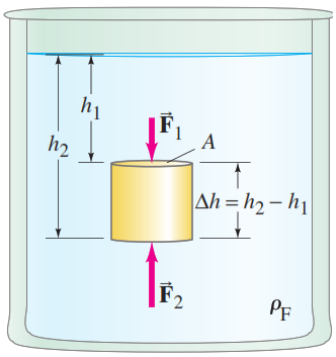

Figure 6. Determination of the Buoyant Force (Giancoli, 2016: 268)

Figure 6 shows that the fluid exerts a pressure $P_1 = \rho_F g h$ on the top surface of the cylinder. The force caused by this pressure on the top of the cylinder is $F_1 = P_1 A = \rho_F g h_1 A$, and its direction is downward. Similarly, the fluid exerts an upward force on the bottom surface of the cylinder given by $F_2 = P_2 A = \rho_F g h_2 A$. The net force on the cylinder, exerted by the fluid pressure, is the buoyant force, $\vec{F_B}$, which acts upward and has a magnitude given

by the following equation:

$$F_B = F_2 - F_1 = \rho_F g A(h_2 - h_1)$$
$$F_B = \rho_F g A \Delta h$$
$$F_B = \rho_F V_g$$
$$F_B = m_F g$$

where $V = A\Delta h$ is the volume of the cylinder; the product $\rho_F V$ is the mass of the fluid displaced, and $\rho_F V_g = m_F g$ is the weight of the fluid that occupies the same volume as the cylinder. Thus, the buoyant force on the cylinder is equal to the weight of the fluid displaced by the cylinder. This result holds regardless of the shape of the object. This finding is known as **Archimedes' Principle**, which states that "the buoyant force on an object submerged in a fluid is equal to the weight of the fluid displaced by the object" (Giancoli, 2016). The term "displaced fluid" refers to the volume of fluid equal to the volume of the object that is submerged (or the part of the object that is submerged). If the object is placed in a glass or tank initially filled with water to the brim, the water that overflows represents the water displaced by the object.

This Archimedes' principle applies to a boat floating on the surface of the water. A boat can float on the surface of the water because it experiences an upward buoyant force from the water, and its weight is equal to the weight of the water displaced by the boat (Halliday et al., 2014). This buoyant force plays a role in maintaining the balance of the boat and minimizing its sinking when both teams are rowing with great force.

6. Work and Energy

The discussion of work and energy encompasses four interrelated components: work, energy, kinetic energy, and potential energy. In the context of the traditional sport of Besei Kambe, the entire process of the boat moving can be considered as work. This is because the fundamental component of work is the displacement of an object due to a force (Pratiwi & Kuswanto, 2024). The work done on an object by a constant force (constant in both magnitude and direction) is defined as the product of the displacement magnitude multiplied by the component of the force that is parallel to the displacement (Giancoli, 2016) (see Figure 7).

Figure 7 shows that in the Besei Kambe tradition, displacement occurs when the boat moves from its initial position ($\vec{\mathbf{d}}$). In equation form, work is written as:

$$W = F_{\parallel} d$$

where $F_{\parallel}$ is the component of the constant force $\vec{\mathbf{F}}$ that is parallel to the displacement $\vec{\mathbf{d}}$. In the case of Besei Kambe, $F_{\parallel} = F_R$, which is the net or resultant force acting on the object.

The concept of kinetic energy applies throughout the displacement of the boat. This is because kinetic energy is influenced by both mass and velocity. The faster the boat moves, the greater its kinetic energy while moving. The equation for kinetic energy is:

$$KE = \frac{1}{2}mv^2$$

where m is the mass of the boat (kg) and v is the velocity of the boat (m/s).

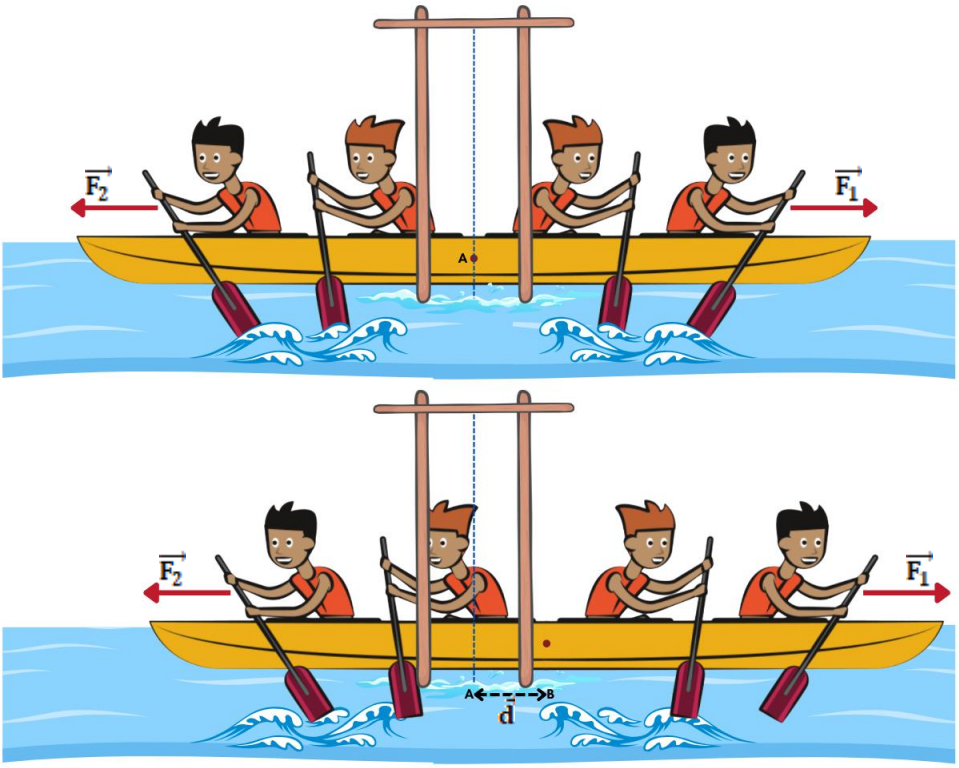

Figure 7. Illustration of The Work Concept in Besei Kambe

Next, the total work (W_{net}) done on the boat can also be written with the following equation:

$$W_{net} = \Delta KE = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$$

where v_1 is the initial velocity of the boat (m/s) and v_2 is the final velocity of the boat (m/s).

7. Momentum and Impulse

When the boat moves, it possesses significant momentum. It is important to remember that momentum is the

product of an object's mass and velocity ($\vec{p} = m.\vec{v}$) (see Figure 8). Therefore, the greater the mass and velocity of the boat's movement, the greater its momentum. As the boat moves forward, it has momentum in the forward direction. If the boat stops (e.g., due to water friction), its momentum decreases. The role of momentum becomes evident as the rowed boat moves faster.

Figure 8. Momentum Occurs When the Boat is Moving

Impulse is the change in momentum of an object that occurs due to a force applied over a short period of time ($\vec{J} = \vec{F}.\Delta t = \Delta\vec{p}$)(Pratiwi & Kuswanto, 2024). In the traditional sport of Besei Kambe, when the oar pushes the water backward (action), the water exerts a reactive force forward (reaction) on the boat. This force acts over a short time interval (Δt), generating an impulse that changes the boat's momentum, causing it to move forward. The role of impulse in this case is to provide the driving force for the boat to move. The harder the rowing, the greater the impulse and the change in momentum. The longer the oar stays in the water, the greater the impulse. In conclusion, when rowing the boat, we apply the concept of impulse to change the boat's momentum. The greater the force and the time the oar is in contact with the water, the greater the change in the boat's momentum, causing the boat to move faster. This principle is also related to Newton's Laws of Motion and the Conservation of Momentum, where the system (boat + water) will try to maintain the total momentum. As the oar pushes the water backward, the boat gains momentum forward.

Conclusion

Based on the research and discussion above, it can be concluded that there are several physics concepts in the traditional sport “Besei Kambe”, namely: Newton's Third Law: action and reaction, net force, Newton's Second Law of Motion, frictional force, Archimedes' principle: buoyant force, work and energy, and momentum and impulse. This article emphasizes the value of incorporating local wisdom, such as the "Besei Kambe" tradition, into physics education. By integrating cultural practices into learning materials, educators can foster more engaging and meaningful learning experiences for students while preserving cultural heritage.

Recommendations

This article can serve as an inspiration for educators to teach physics in schools. Teachers can delve deeper into physics concepts by exploring phenomena and events in their surroundings, including local wisdom. By

developing culturally-based physics learning materials, teachers can create more engaging and relevant learning experiences for students. It is hoped that by connecting physics concepts to students' everyday experiences, students' motivation to learn will significantly increase. Additionally, this research can help students appreciate cultural diversity and deepen their understanding of local wisdom.

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The Effectiveness of Problem-Based Learning (PBL) on Problem- Solving Skills in Science: A Literature Review

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Abstract: Entering the 21st-century education, problem solving skills have become one of the most crucial competencies for students. An effective learning model focusing on students' problem-solving abilities is necessary to enhance these skills. Various learning models have been developed and implemented across different levels of education. This research aims to gain information about efforts to improve problem solving skills in science learning. The PRISMA model, which has several established criteria, is the systematic literature review model. The review method was chosen to identify research journals with the keywords "problem solving skills in science learning," focusing on international journals indexed in Scopus. 42 articles were reviewed based on author, year, learning model, research method, problem solving skills, and research findings. Based on the review of these articles, implementing Problem Based Learning (PBL) with a percentage of 43% and Project-Based Learning (PJBL) with 19% were the most frequently used approaches to enhance problem solving skills. The most frequently used research method for improving problem solving skills in science learning was the quantitative method with a quasi experimental design. Furthermore, the majority of the publications were from the years 2020-2021. This research indicates that learning using the Problem Based Learning (PBL) model is considered highly effective in significantly impacting students' skills and engagement in learning. Therefore, this research can contribute to the field of education, particularly in evaluating science learning to enhance problem solving skills.

Keywords: Problem Solving Skills, Problem Based Learning (Pbl), Systematic Litarature Review

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Introduction

In the 21st-century education era, problem solving skills have become one of the most crucial competencies for students. These skills are relevant in academic contexts and daily life, where identifying, analysing, and finding practical solutions is highly necessary (Sellnow, 2009; Voogt & Roblin, 2019). Indeed, problem solving skills are a key competency that has garnered significant attention. This skill set is essential in professional environments and everyday situations, particularly when addressing issues that demand information analysis, evaluation, and synthesis (OECD, 2019). In the educational realm, particularly in science education, problem solving skills are regarded as a crucial component that fosters critical, creative, and systematic thinking among students as they seek to comprehend natural phenomena and utilise scientific knowledge to address authentic problems (Hmelo-Silver, 2020).

As a discipline grounded in investigation and experimentation, science learning holds significant potential for developing problem solving skills (Bybee, 2019). Through appropriate pedagogical approaches, students can be guided to identify problems, formulate hypotheses, design experiments, analyse data, and draw conclusions (Zimmerman, 2020). This process strengthens students' conceptual understanding and cultivates their logical and systematic thinking abilities (National Research Council, 2021). However, despite the widespread recognition of the importance of these skills, their practical application within science education still encounters several obstacles, including teachers' insufficient understanding of effective instructional strategies, resource limitations, and a heavily loaded curriculum (Tytler, 2020).

In recent years, research on problem solving skills in science learning has experienced a significant increase (Anderson et al., 2021). The period of 2019-2023, in particular, has witnessed various innovations and novel approaches aimed at enhancing the effectiveness of science education in developing these skills (Lin et al., 2022). From integrating digital technology and project-based learning to collaborative learning methods, numerous studies have attempted to explore optimal strategies for promoting students' mastery of problem solving skills (Bell, 2020). However, with the growing body of research, there is a need to synthesise these findings to provide a comprehensive overview of current trends and developments (Gough et al., 2021).

Systematic Literature Review (SLR) is an effective method for systematically and structurally analysing and synthesizing research findings (Kitchenham & Charters, 2020). By employing this approach, researchers can identify patterns, trends, and gaps in the existing literature and provide recommendations for future research and practice (Petticrew & Roberts, 2021). In the context of problem solving skills in science learning, SLR can help reveal the most effective strategies, factors influencing success, and challenges that still need to be addressed (Tsai et al., 2022). Furthermore, SLR can provide insights into how these skills are integrated into curricula and teaching practices across various educational contexts (Erdogan, 2023).

This article aims to conduct a systematic literature review of research on problem solving skills in science learning published between 2019 and 2023 (Smith et al., 2023). With a focus on this period, this article seeks to

identify key trends, innovations, and significant findings that can inform educators, researchers, and policymakers in their endeavours to enhance the quality of science education (Johnson & Lee, 2023). Through this comprehensive review, it is anticipated that this article will significantly contribute to advancing both the theoretical underpinnings and practical applications of science education, especially concerning the reinforcement of problem solving skills as a core 21st-century competency (Brown et al., 2023).

This article outlines the findings of a literature study regarding trends in problem solving skills within science education, representing a review of research articles published in international journals indexed by Scopus. This research aims to comprehensively answer the following research questions:

Q1: What is the trend in the number of research studies on problem solving skills in science learning from 2019 to 2023??
Q2: What types of research are frequently used to investigate problem solving skills in science learning?
Q3: What learning models effectively enhance problem solving skills in science learning?
Q4: What does the literature review of articles reveal about the findings concerning effective learning models for enhancing problem solving skills in science education?

Method

This research constitutes a literature review focusing on problem solving skills within science education. The articles utilized as sources were sourced from international journals indexed in Scopus, which have been screened to gauge advancements in science and technology. 42 articles relevant to the research topic were identified after the identification phase. The articles included in this analysis were published within the period of 2019 to 2023 and specifically address problem solving skills in science learning. The systematic literature review model employed in this study is the PRISMA model, supplemented by several criteria established by the authors. The reviewed articles were selected based on the following criteria:

1) The study must be indexed in the Scopus database;
2) The article must discuss problem solving skills in the context of science learning;
3) The study must be published in the form of a journal article;
4) Conference proceedings were excluded;
5) The article must be available as open access.

The article selection process using the PRISMA method is illustrated in Figure 1.

The data obtained from each reviewed article was subsequently analysed, with several investigated indicators tailored to specific aspects that fulfilled the criteria established by the reviewers. These indicators encompassed the publication year, research type, subject area, topic, learning model, methodology, and outcomes. The correlation between titles and abstracts was analysed using Vosviewer software, whereas the remaining indicators were analysed manually. Subsequently, the gathered data was presented as tables, line graphs, and bar

charts.

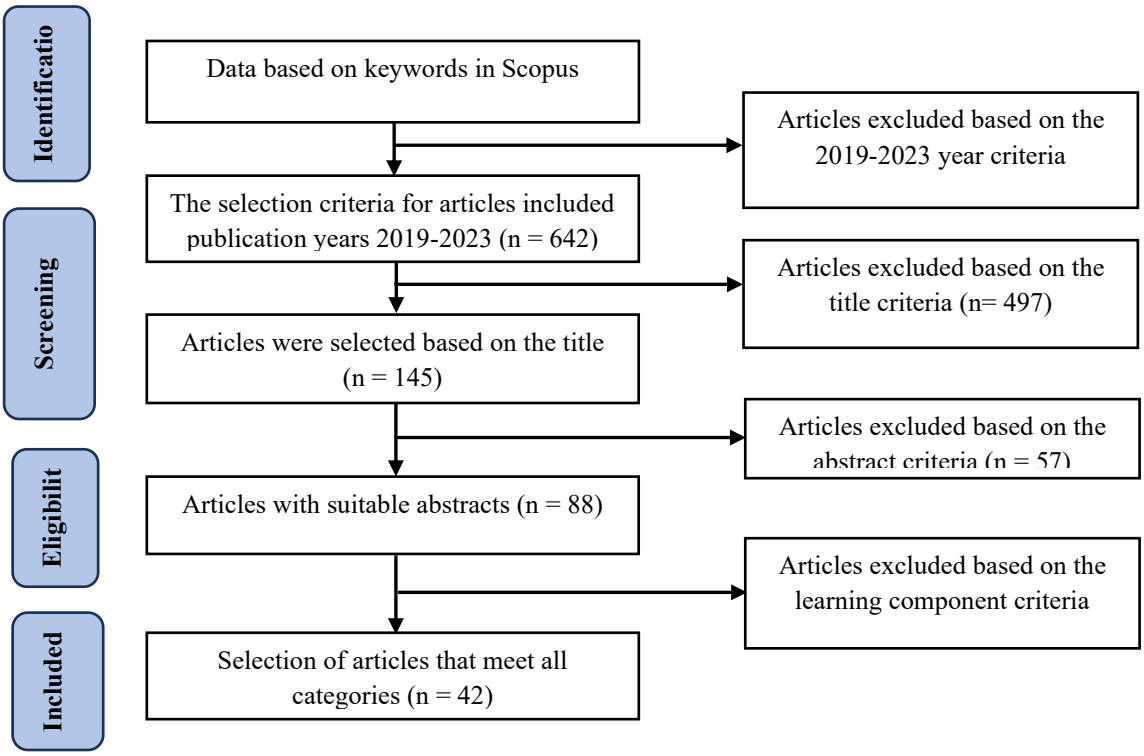

Figure 1. Flow Diagram PRISMA

Results and Discussion

The researchers' initial search yielded 88 articles from various Scopus-indexed international journal sources relevant to problem solving skills. However, following the screening process, 42 articles were identified as meeting the criteria for problem solving skills within science education, presented in Table 1.

Table 1. Articles That Meet the Criteria

No	Author	Index By
1	Abidin & Hariyono. (2020)	Scopus
2	Adikana et al. (2020)	Scopus
3	Agnezi & Festiyed. (2023)	Scopus
4	Agustoni et al. (2021)	Scopus
5	Alfiana et al. (2021)	Scopus
6	Angriani et al. (2021)	Scopus
7	Anindya & Wusqo (2020)	Scopus
8	Astuti et al. (2020)	Scopus
9	Bakri et al. (2021)	Scopus

10	Bakri & Dwijayanti. (2022)	Scopus
11	Cahyono et al. (2020)	Scopus
12	Dibyantini et al. (2021)	Scopus
13	Dwikoranto et al. (2023)	Scopus
14	Gunawan & Lagut. (2020)	Scopus
15	Harefa & Purba. (2020)	Scopus
16	Hasan et al. (2021)	Scopus
17	Hidaayatullaah et al. (2020)	Scopus
18	Himawan & Wilujeng. (2020)	Scopus
19	Ina Sukma Dewi et al. (2020)	Scopus
20	Jannah et al. (2021)	Scopus
21	Lestari et al. (2021)	Scopus
22	Malik et al. (2019)	Scopus
23	Mashluhah et al. (2019)	Scopus
24	Meutia et al. (2020)	Scopus
25	Monsang et al. (2021)	Scopus
26	Muhlisin et al. (2022)	Scopus
27	Parno, Zulaikah, et al. (2021)	Scopus
28	Parno et al. (2020)	Scopus
29	Parno, Kusairi, et al. (2021)	Scopus
30	Parno, Anggraini, et al. (2021)	Scopus
31	Prahani et al. (2021)	Scopus
32	Pratiwi et al. (2021)	Scopus
33	Pratomo et al. (2019)	Scopus
34	Purwaningsih et al. (2020)	Scopus
35	Qotrunnada et al. (2023)	Scopus
36	Ramli et al. (2021)	Scopus
37	Saputri et al. (2021)	Scopus
38	Sayekti et al. (2020)	Scopus
39	Siswanto et al. (2022)	Scopus
40	Suryani et al. (2020)	Scopus
41	Taharu et al. (2020)	Scopus
42	Yuliati et al. (2020)	Scopus

The interrelationships between articles were identified based on their titles and abstracts. The analysis was conducted by considering a broad range of references, thus enhancing the effectiveness of the cluster distribution. Concerning the relationship between titles and abstracts, Vosviewer software visualized words forming interconnected networks, leading to the appearance of several clusters. Consequently, any article sharing keywords with other articles was categorized within the same cluster, as illustrated in Figure 2.

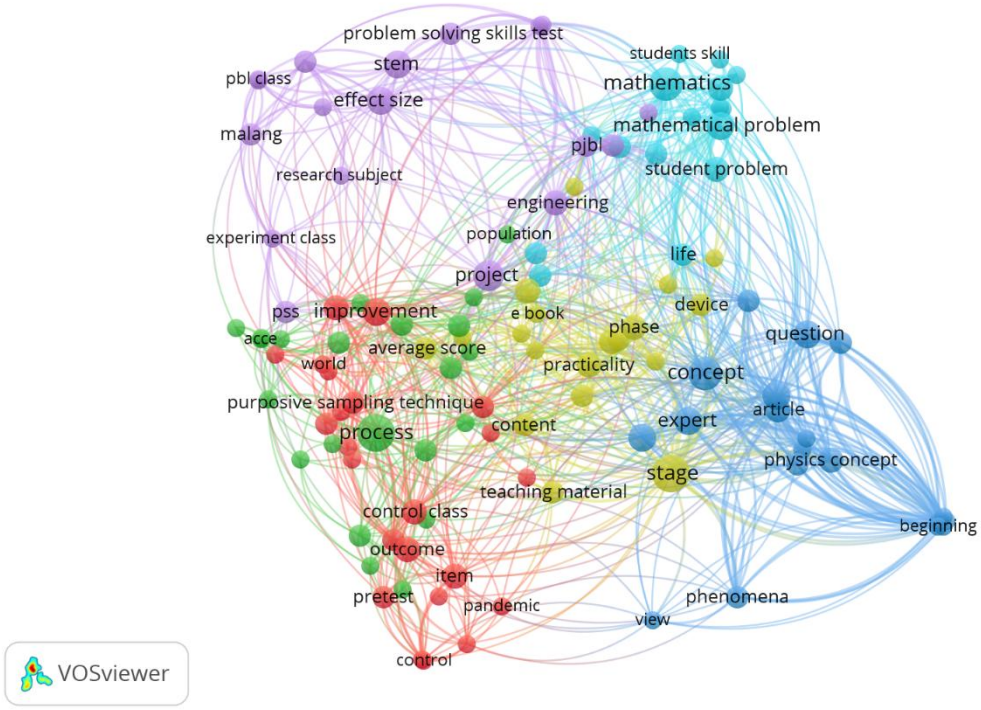

Figure 2. Vosviewer Screenshot of Keyword Relationships

Based on the analysis results, a total of 117 items/words were identified. Subsequently, keywords that describe the research were selected and grouped into six color-coded clusters: red, green, blue, yellow, purple, and light blue. According to the mapping presented in Figure 2, the keywords within each cluster are organized as depicted in Table 2.

Table 2. Problem Solving Research Cluster in Science Learning

Cluster Colors	Keywords in Clusters
Red	Control, control class, cps, essay test, experiment, group pretest posttest design, improvement, item, mean, outcome, pandemic, person, posttest control group design, preliminary study, present study, pretest, purposive sampling technique, sig, sma negeri, treatment, west java, world, Yogyakarta.
Green	21st century skill, acce, challenge, control group, evaluation, existence, experimental group, factor, group pre test, high school student problem, industrial revolution, inquiry, mastery, population, post test, post test design, pre experimental design, process, profile, significant difference, student activity, students physics problem.
Blue	21st century, article, beginning, chapter, concept, dick & carey model, expert, hypothesis, phenomena, physics concept, physics textbook, question, research method, senior high school student, technology, textbook media expert, tpack, video, view.

Yellow	Autentic learning, average score, biggest challenge, content, data analysis technique, development research, device, disseminate, e-book, phase, plomp, practicality, stage, teaching material, ultilization, validation, validator, validity, validity criterium.
Purple	Comparison class, effect size, electromagnetic induction, engineering, experiment class, formative assessment, malang, mixed method, PBL class, PJBL, PJBL Stem, problem solving skills, project, PSS, research subject, stem, stem approach, syntax.
Baby Blue	Attention, data collection, function, junior high school, life, mathematical problem, mathematics, order, participant, PBL model, skills test, student problem, student mathematical problem, student skill, term, year.

The visualization in Figure 3 identifies an even distribution of strongly correlated concepts. Further analysis indicates that this uniform data dispersion has a significant relationship with problem solving skills. The term "siswa" (student) represents the research participants, "model" denotes the approach employed in the research, and "tes" (test) functions as the instrument for assessing problem solving skills.

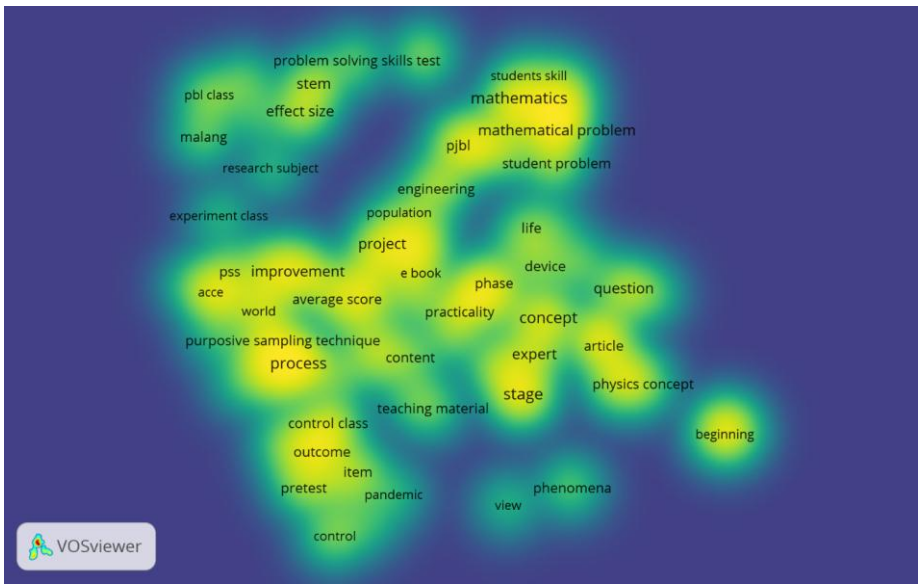

Figure 3. Vosviewer Displays Density Visualization

The mapping results based on titles and abstracts, as visualized by VOSviewer in Figure 3, can be further described upon detailed re-examination of the articles based on their publication year, research type, subject of investigation, and learning model within science education. The problem solving skills analysis process was conducted as follows.

Number of Publications

The number of article publications reflects the intensity of research on a particular topic. Figure 4 indicates that

research on problem solving skills in science learning in Scopus has been ongoing since 2019-2023. A significant increasing trend was observed in 2020-2021, with the number of publications peaking at seventeen and sicteen articles. This phenomenon suggests a growing interest among researchers in exploring problem solving skills within the context of science learning. Nevertheless, the number of publications decreased in the subsequent year.

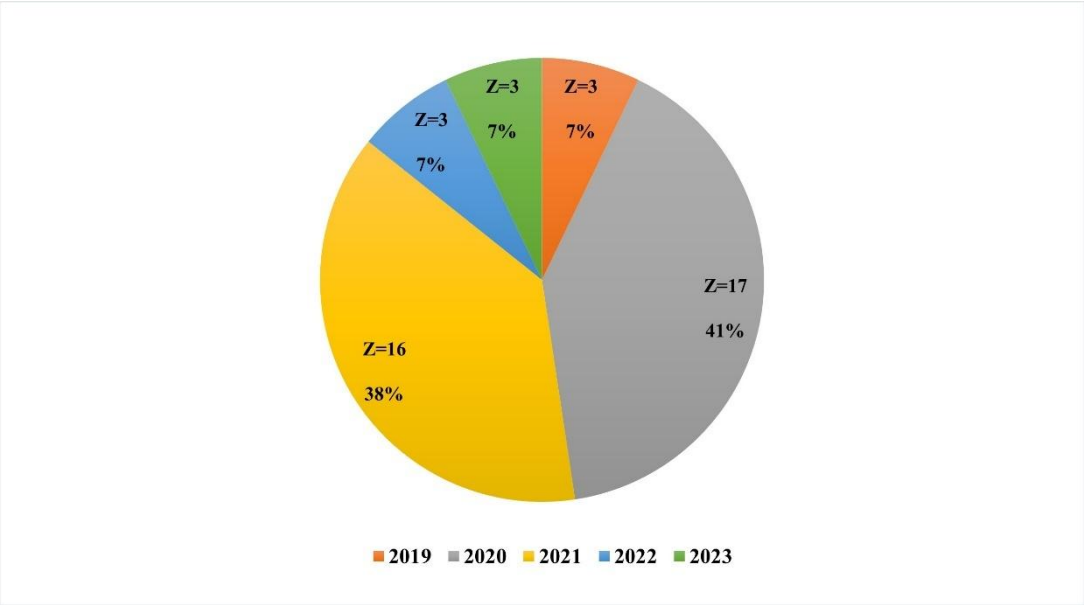

Figure 4. Distribution of Publication Years

Research findings generally stem from researchers' sensitivity to common issues frequently encountered in their surroundings (Maharani, 2023). The primary driving force behind much research is a reaction to contemporary issues holding social significance (Fajri, 2024). A notable challenge at present is the inadequate level of problem solving skills among students in Indonesia (Prasetyo et al., 2021). Consequently, scientific inquiry is a potent instrument for tackling these challenges. Through research, scholars can pinpoint the most effective pedagogical approaches and instructional resources for significantly enhancing students' problem-solving abilities (Pramesti, 2023). Hence, a rise in the number of scholarly publications centred on problem solving skills is anticipated to considerably impact the transformation of education within Indonesia (Fajri, 2024). This perspective is consistent with the study's primary aim: to offer insights and enhancements to current educational practices (Maharani, 2023).

Research Type

The focus of the research is determined by the type and design of the research implemented. Table 3 indicates that quantitative research methods are the most common approach used by researchers in investigating problem solving skills. A total of 24 published articles, representing 57.2%, employed quantitative research methods. This finding aligns with prior research outcomes demonstrating that researchers exhibit a tendency to favor quantitative research designs when undertaking studies in the domain of education, especially science learning,

in comparison to other research methodologies (Setiawan & Musaffak, 2021; Nabilah & Jumadi, 2022). Consequently, the inclination towards quantitative methodologies in educational research, specifically within science learning, is becoming ever more apparent and pertinent.

Table 3. Distribution of Articles Based on Research Methods

Research Method	Z	Percentage
Quantitative	24	57,2 %
Qualitative	3	7,2 %
R & D	12	28,4 %
Mixed Method	3	7,2 %
Z	42	100%

Besides outlining the research types, this study also intends to elucidate the distribution of research designs, as presented in Table 4, selected by the r researchers. Table 4 indicates a higher prevalence of quasi-experimental research designs compared to other designs, with 18 published articles. Within quasi-experimental research designs, researchers seek to compare the effectiveness of different treatments in enhancing problem solving skills (Azizah, 2023). Prior studies have also demonstrated the frequent use of quasi-experimental designs within educational settings to assess the efficacy of diverse learning interventions (Abraham & Supriyati, 2022). This underscores that this approach offers valuable insights regarding the impact of interventions on students' learning processes.

Table 4. Distribution of Articles Based on Research Design Methods

Research Methods			Z
Quantitative	Experimental	Quasi Experiment	18
		Pre-Experiment	5
	Non-Experimental	Deskriptif Kuantitatif	1
Qualitative		Deskriptif Kualitatif	3
R & D		R&D ADDIE	3
		R&D Plomp’s	2
		R&D 4D	4
		R&D Borg & Gall	3
Mixed Method		Explanatory Design	2
		Embedded Design	1
			42

Learning Models

This research presents a representation of findings on various types of learning models related to problem solving skills. Forty-two Scopus-indexed articles pertaining to learning model findings within the realm of

problem solving skills were identified. Subsequently, an analysis was conducted to ascertain the percentage of learning models linked to students' problem solving skills, as presented in Table 5 below.

Table 5. Distribution of Learning Models Related to Problem solving skills

No	Learning Models	Z	Percentage
1	Problem Based Learning (PBL)	18	43%
2	Project Based Learning (PJBL)	8	19%
3	Kooperatif Learning	4	10%
4	Learning Cycle	2	5%
5	Group Investigation Learning	2	5%
6	Theory of Inventine Problem Solving (TRIZ)	1	2%
7	Blended Learning	2	5%
8	Reading, Identification, Analysis and Self-reflection (RIAS)	1	2%
9	Inquiry	2	5%
10	Creative Problem Solving (CPS)	1	2%
11	Osborn simple feedback learning	1	2%
		42	100%

Table 5 illustrates that the articles chosen for review comprise 42 articles employing diverse learning models in the context of problem solving skills. The results in Table 6 indicate that the most frequently used learning model in research on problem solving skills in science learning is the problem based learning (PBL) model, with 18 articles, representing 43%. This suggests that the problem based learning (PBL) model is the most prevalent in the reviewed literature on students' problem solving skills. Within the context of science learning, problem solving skills pertain to problem-based steps that are highly advantageous in attaining learning goals. Within technology education, the problem based learning (PBL) model is frequently associated with real-world issues. This model holds the potential to improve students' problem solving skills, deepen their comprehension, and foster greater engagement in the learning process, as learning activities are student-centered and enable them to connect problems with real-world scenarios (Apriwanda & Hanri, 2022; Sari et al., 2017). Hence, this model can be considered effective in eliciting students' problem solving skills.

Results of the Literature Review of Articles

In this study, the evaluation results of articles employing the problem based learning (PBL) model within science education are categorized based on the author, publication year, methodology, and findings of each article. This literature review was undertaken to assess the significance of the findings across all 18 articles to substantiate the effectiveness of the problem based (PBL) model in enhancing students' problem solving skills. The review outcomes are presented in Table 6.

Table 6. Results of the Article Review

Author and Year	Method	Findings
(Hidaayatullaah et al., 2020b)	Quantitave	The research results indicate that the implementation of PBL has an effect on students' problem-solving abilities in both the experimental and replication groups.
(Alfiana et al., 2021)	R&D	Problem based learning (PBL)-STEM with formative assessment is considered very feasible to improve problem solving skills in the topics of heat and temperature.
(Astuti et al., 2020)	R&D	The research findings indicate that the test instrument designed to assess students' problem solving skills is proven to be valid and reliable.
(Dwikoranto et al., 2023)	R&D	PBL-based teaching modules have shown improvement and are deemed suitable for enhancing students' problem solving skills.
(Gunawan & Lagut, 2020)	Quantitave	The result of the article reveals that after applying the problem based learning model on the probability topic, students show an improvement in problem solving skills.
(Jannah et al., 2021)	Quantitave	The research findings indicate that students' problem solving skills improved after implementing the PBL model. These results suggest that the PBL model contributes to enhancing students' problem-solving abilities.
(Monsang et al., 2021)	Quantitave	The findings of this study show that science students in the experimental group are significantly higher compared to those in the control group.
(Parno, Kusairi, et al., 2021)	Quantitave	The research findings indicate that the STEM approach with formative assessment in Problem based learning (PBL) has a significant impact on the development of students' problem solving skills (PSS), especially in the topic of static fluids.
(Ramli et al., 2021)	R&D	The research findings indicate that the e-book developed, designed based on the Problem based learning model is effective in improving students' problem-solving abilities in physics field.
(Suryani et al., 2020)	Mixed Method	The implementation of the Problem based learning (PBL) model can enhance students' problem solving

		skills by categorizing them into three categories: high achievers, moderate achievers, and low achievers based on Polya's problem-solving indicators.
(Agustoni et al., 2021)	R&D	The research results show that all indicators fall into the good and very good categories. It can be concluded that the indicators for problem-solving related to alternative energy sources show significant results.
(Himawan & Wilujeng, 2020)	Quantitave	The research results show an influence of the Quick on The Draw learning model, assisted by an optics learning book integrating Pancasila values, on problem solving skills.
(Ina Sukma Dewi et al., 2020)	R&D	The development of BLCS (Bruner's theory, Local Culture, and Scaffolding) learning tools has proven to be valid, practical, and effective in enhancing mathematical problem solving skills.
(Parno, Kusairi, et al., 2021)	Quantitave	This research shows that the STEM approach with formative assessment in Problem based learning (PBL) has a significant impact on developing students' problem solving skills (PSS), particularly on the topic of static fluids.
(Qotrunnada et al., 2023)	Quantitave	There is a need to improve teaching strategies and materials to enhance students' problem solving skills in dynamic fluid topics, and the ACCES indicator is a reliable method for assessing these skills.
(Taharu et al., 2020)	Quantitave	These findings indicate that PBL is more effective than direct instruction in improving students' problem solving skills and understanding of biology concepts, particularly considering students' academic abilities.
(Dibyantini et al., 2021b)	Quantitave	The research results show that the improvement in students' generic chemistry skills using the PBL model is higher compared to the direct instruction model, indicating that PBL is effective in enhancing concept mastery and problem solving skills in organic chemistry.
(Mashluhah et al., 2019)	Quantitave	Problem based learning models have proven effective for addressing the problem solving skills in basic science for school students.

Based on the findings regarding the significance of the literature review to assess the effectiveness of the

problem based learning (PBL) model for students' problem solving skills, presented in Table 6, the results demonstrate that the problem based learning (PBL) model is effective in improving students' problem solving skills, with an effectiveness level ranging from moderate to high. These outcomes were derived from a comprehensive literature review of the findings across 18 articles. These findings significantly bolster the present study and future research endeavours in conducting literature reviews and undertaking more intricate investigations concerning the problem based learning (PBL) model with varying variables. Based on the research outcomes concerning the effects of problem based learning (PBL) within the educational domain, 95% of the studies demonstrate that the PBL model significantly impacts and enhances both the learning process and problem solving skills. According to Kirschner et al. (2006), this is attributed to the fact that the problem based learning (PBL) model is a social constructivism model capable of fostering an active learning environment among learners.

Conclusion

Based on the analysis of research publications concerning problem solving skills in science education between 2019 and 2023, a significant surge in research interest in this domain was observed. Research activity peaked in 2020 and 2021, with 17 and 16 Scopus-indexed articles published, respectively. Most studies predominantly employed a quantitative approach, with the quasi-experimental design being the most frequently selected. In efforts to enhance students' problem solving skills, the problem based learning (PBL) model and the project-based learning (PJBL) model emerged as the most frequently applied approaches. The findings of this systematic literature review, encompassing 42 articles, can be used as a reference for future research, especially concerning the development of problem solving skills in science education in Scopus. The application of the problem based learning (PBL) model in science education is supported by numerous research studies and surveys that underscore its efficacy. This study indicates that instruction employing the problem based learning (PBL) model is deemed highly effective in significantly impacting students' skills and engagement in the learning process. Consequently, the problem based learning (PBL) model can serve as a valuable reference for implementation in the teaching and learning process. The findings of this systematic literature review, encompassing 42 articles, can be used as a reference for future research, especially concerning the development of problem solving skills in science education.

Recommendations

This article can inspire for future researchers to explore information regarding the application of Problem based learning (PBL) in science education to examine the achievement in enhancing science problem solving skills.

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Barriers to the Implementation of STEM Education at the Middle School Level

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Abstract: The implementation of STEM education has become a commitment of Indonesian education policymakers to be applied in schools across the country. The *Merdeka Curriculum* is the current national curriculum in effect. Its greater flexibility allows STEM education to be implemented not only in intraclass learning but also in *P5* (Project-Based Strengthening of the Pancasila Student Profile) activities. This study aims to identify the challenges faced by junior high school science teachers in Indonesia in implementing STEM education. The method used involved conducting interviews with 40 science teachers from various provinces, representing major islands across Indonesia, followed by qualitative analysis. The results showed that there are ten challenges faced by teachers in implementing STEM, with limited understanding of STEM and inadequate learning facilities being the most significant obstacles. Nevertheless, teachers demonstrated strong enthusiasm to continue learning and innovating in the implementation of STEM education in their classrooms.

Keywords: STEM, Science learning, Science education, Learning barriers, STEM Learning

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Introduction

The advancement of the times, accompanied by developments in science and technology, has had a significant impact on various aspects of life. Education is one such area that has been heavily affected, making it necessary for the education provided to future generations to focus on 21st-century skills that align with the dynamics and demands of the modern era (Ozturk, 2023). Twenty-first-century skills refer to competencies that must be possessed by individuals of productive age in modern times to meet the challenges of the era.

Many graduates of secondary schools, diploma programs, and higher education institutions have been found lacking in critical thinking and problem-solving skills. The ASEAN Business Outlook Survey (2014) revealed that Indonesia is one of the main destinations for foreign investment within the ASEAN region. While investment is generally a positive indicator, it was also found that Indonesia's attractiveness is partly due to the availability of low-skilled, low-wage labor (Sihotang, 2019, p. 5). In various developed countries, the implementation of STEM education has proven to drive innovation, economic growth, and technological advancement. Consequently, many countries, including Indonesia, have begun adopting this approach into their education systems.

Education plays a central role in improving the skills of human resources in Indonesia. Schools are expected to prepare generations capable of competing globally. The government continues to pursue equal access to quality education through various programs. Learning quality is continually updated through curriculum reforms. The *Merdeka Curriculum* has been the nationally implemented curriculum since 2022. In this curriculum, science learning outcomes consist of two main elements: scientific understanding and process skills.The construction of knowledge forms an essential foundation for developing 21st-century skills. Students must possess a solid base of knowledge to effectively apply their skills in real-world, relevant contexts (Stehle, 2019, p. 3). STEM is considered an alternative learning approach for building 21st-century competencies (Ilma, 2023, p. 134). The STEM approach is defined as the integration of at least two disciplines (Stehle, 2019, p. 530). Implementing STEM projects has been shown to be more effective in enhancing students' critical thinking skills (Rizki, 2024, p. 537), with critical thinking being a key component of 21st-century competencies. STEM education developed through the Engineering Design Process (EDP) equips students with employability skills and independence. Saraç (2018), as cited in Dörterler (2021, pp. 541–542), reported that the impact of STEM practices showed a significant effect size of 0.820 on science process skills. Furthermore, the implementation of STEM can enhance students' science process skills (Hiğde, 2022, p. 1).

However, problems have arisen because the implementation of STEM education in Indonesia has not yet met the government's expectations. Various challenges in implementing STEM at Indonesian schools have been identified. Therefore, this study aims to explore the barriers to STEM implementation at the junior high school level in Indonesia.

Method

This study employed a qualitative research design. Data were collected through Zoom interviews with 40 junior high school science teachers (IPA) from different provinces, representing each of Indonesia’s major islands. The interview protocol consisted of open-ended questions focusing on the barriers and challenges encountered in implementing STEM education at the junior high school level.

Data were analyzed using an interpretative method that sought to uncover the meaning and perspectives of the respondents. The analysis stages included data collection, reading through the entire interview transcripts, classification, and drawing conclusions from each question. The questions used for data collection were as follows:

1. What do you know about STEM education?
2. In your opinion, how prepared are you to teach STEM in your classroom?
3. Have you ever participated in any STEM education training?
4. Has your school provided adequate facilities and infrastructure to support STEM education?
5. What are the main obstacles you encounter in implementing STEM education in the classroom?

Further questions were developed by the researcher based on the respondents' answers. The teachers interviewed included both private and public school teachers aged between 28 and 40 years. They came from provinces located on the islands of Sumatra, Java, Kalimantan, Bali, Papua, Sulawesi, and Nusa Tenggara, with teaching experience ranging from 5 to 15 years.

Results and Discussion

Teachers' Understanding of STEM Education

The interview results indicated that teachers understand STEM education as an approach that integrates four disciplines—science, technology, engineering, and mathematics—seamlessly within the learning process. Teachers recognized that STEM education is problem-solving-oriented and project-based, aiming to train students to find solutions to real-world issues, thereby enhancing their creativity and critical thinking skills. However, the findings also revealed that teachers perceived STEM learning as requiring an equal integration of all four disciplines, which is inconsistent with Bybee's explanation in *The Case for STEM Education: Challenges and Opportunities*. According to Bybee, STEM integration involves at least two disciplines, and the integration does not necessitate equal emphasis across all four fields. This suggests that Indonesian junior high school science teachers' understanding of the STEM concept is not yet fully aligned with the actual theoretical framework.

Readiness to Teach STEM

The interviews revealed that 17 out of 40 teachers were categorized as moderately ready to implement STEM education in their classrooms. Although they expressed willingness and a basic understanding of STEM, several aspects still needed further learning. Teachers admitted that they had yet to fully grasp interdisciplinary integration within STEM, and that limited school facilities posed additional challenges. Nevertheless, many found creative solutions by utilizing locally available materials and maintained a willingness to learn while practicing. Previous experience with project- or problem-based learning also contributed to their readiness.

Seven teachers were categorized as fully ready to implement STEM, as they had previously practiced STEM-based learning in their classrooms and had even trained their colleagues in its application. Examples of projects they had conducted included solving waste management issues, developing renewable energy projects, creating safe knives for the visually impaired, building mini drones, and designing earthquake detectors. Meanwhile, four teachers stated that they were not ready to implement STEM due to a lack of experience, absence of training opportunities, and fear of making mistakes, although they remained open to future learning. Twelve teachers reported being not fully prepared, citing difficulties in designing STEM-based learning activities for junior high school students and a lack of expected collaboration support from colleagues.

When viewed by regional distribution, teachers from cities such as Padang, Medan, Makassar, Manado, Pontianak, and cities in Java showed greater readiness for STEM implementation, largely due to easier access to information and training opportunities provided by universities, as well as training centers like PPPPTK (now renamed BGP and BBGP). These institutions offered more precise and applicable knowledge for teachers.

STEM Training for Teachers

The demand for STEM training is relatively high, with many teachers expressing a need for practical, hands-on training rather than just theoretical exposure. Nine out of the 40 respondents indicated that they had never attended STEM training nor sought out independent learning opportunities, citing limited access to information, lack of invitations from relevant institutions, and minimal support from their work environments as reasons.

Conversely, 31 teachers reported having been exposed to STEM through either online or offline training sessions or peer sharing. They accessed training via MGMP (Subject Teachers' Forum), teacher learning communities, online training providers, universities, BBGP/BGP, or LPMP (Educational Quality Assurance Institute). Some were even self-motivated to learn from fellow teachers knowledgeable in STEM. The data reveal that STEM is not an entirely foreign concept for most junior high school science teachers in Indonesia. However, most training sessions provided only theoretical knowledge without practical guidance on implementing STEM in classroom settings.

Facilities and Infrastructure to Support STEM

Most teachers felt that the facilities and infrastructure available at their schools were still inadequate to support effective STEM learning. While some schools had science laboratories, projectors, and internet-accessible computers, their availability was often limited and insufficient for all students. Moreover, laboratory equipment, practice materials, and technology that could facilitate the integration of science, technology, engineering, and mathematics disciplines were not uniformly available. As a result, teachers frequently needed to improvise using simple tools or available technologies to ensure the implementation of STEM education.

This indicates that significant improvements in school facilities and infrastructure are still needed to optimize STEM-based learning. Further findings from the interviews showed that private schools generally had better supporting facilities for STEM education compared to public schools.

Challenges in Implementing STEM Education

Based on interview results, ten challenges were identified by junior high school science teachers in implementing STEM education, as shown in Figure 1. (1) Uncertain about determining the appropriate assessment method. Teachers reported difficulties in designing STEM assessment rubrics because this learning approach is multidisciplinary and process-oriented. They are not yet accustomed to comprehensively evaluating students' work and lack clear guidelines for assessing the success of STEM learning. (2) Requires a long time to prepare STEM-based learning. Teachers stated that preparing STEM teaching modules takes more time than preparing non-STEM modules. The complexity of planning an integrated learning sequence discourages some teachers from choosing STEM, especially since administrative tasks already consume much of their time.

(3) Students' comprehension ability and learning motivation. STEM learning emphasizes critical thinking, creativity, innovation, and scientific process skills, which some teachers believe do not align with their students' capabilities. These skills are often underdeveloped among students, and low motivation further hinders the implementation. Instead of creating and innovating, students tend to copy existing ideas or rely on the teacher for solutions. This stems from a traditional learning culture where students are accustomed to receiving information passively and memorizing content. As a result, within a semester, problem-solving and scientific inquiry activities occur far less frequently than conventional lessons.

(4) Parental support for students. STEM learning often requires specific tools and materials, which may not be available at schools due to funding limitations. Consequently, teachers sometimes ask students to bring materials from home. For families with lower economic backgrounds, this can be burdensome. Additionally, in some households, parental involvement in supporting children's learning is minimal, with an assumption that schools are solely responsible for the child's development because students spend most of their time at school. (5) Limited duration of teaching and learning activities. The maximum number of students per junior high school class in Indonesia is 32. In private schools, the number is usually lower, around 25, which allows for better individual attention. However, due to space constraints and other factors, many schools operate at full capacity. Managing a large class with only one teacher makes effective STEM implementation challenging. STEM lessons require closer supervision and longer instructional time, yet each lesson is limited to only 35 minutes, making it difficult to deliver STEM education effectively. (6) Support from colleagues. Ideally, STEM education involves interdisciplinary collaboration. However, some teachers find it difficult to collaborate with colleagues who do not perceive STEM as a priority. Many teachers work independently in fulfilling their responsibilities, and change agents are often met with resistance or indifference. This is a critical concern for Indonesia's education system, as modern demands require collaborative efforts to achieve optimal outcomes. (7) Limited school facilities and infrastructure. (8) Lack of understanding on how to implement STEM. (9) Limited

access to affordable STEM learning resources. Among the most commonly cited challenges is inadequate infrastructure, stemming from the perception that STEM requires sophisticated equipment. In reality, approaches like STEM Hackathons offer a simpler and more cost-effective way to implement STEM using available resources. This links to the eighth point—teachers' limited knowledge about STEM in general, including STEM Hackathons—making this the second most frequently mentioned challenge. Teachers also struggle to find STEM learning references in Indonesian that are suitable for junior high school levels. Many Indonesian teachers find it difficult to learn from English-language materials, which dominate the available STEM references. This highlights the need for policymakers to provide more Indonesian-language STEM resources, a process that is currently ongoing. (10) A curriculum system that does not adequately support STEM integration. STEM has not yet been formally mandated in Indonesia's national curriculum. Education authorities such as the local education offices have not implemented special initiatives to encourage schools under their supervision to adopt STEM. In contrast, elite private schools are more familiar with STEM and often implement it in science subjects as part of the core curriculum or as extracurricular activities.

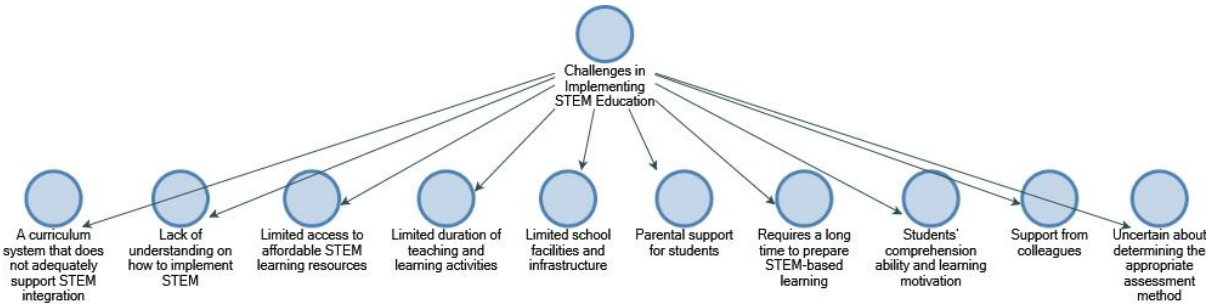

Figure 1. Challenges Faced by Teachers in Implementing STEM Education

Conclusion

Most junior high school science teachers understand STEM education as an integration of science, technology, engineering, and mathematics based on problem-solving. However, there are still misconceptions about the concept of integration. Teachers' readiness to implement STEM is relatively good, although it is hindered by limited understanding, inadequate facilities, and a lack of practical training. Support in terms of infrastructure, instructional time, Indonesian-language references, and the national curriculum system is also still insufficient. Despite these obstacles, teachers demonstrate enthusiasm to keep learning and innovating in applying STEM education in their classrooms.

Recommendations

Future researchers are encouraged to develop classroom-based practical STEM training models, create applicable STEM assessment guidelines, and design STEM learning modules utilizing local resources so that implementation is not dependent on advanced facilities. Further studies could also explore strategies to enhance interdisciplinary teacher collaboration, analyze students' readiness and motivation in STEM learning, and

expand accessible Indonesian-language STEM references for teachers. It is also recommended to evaluate the differences in STEM implementation between public and private schools to identify key success factors, and to examine the feasibility of explicitly integrating STEM into the national curriculum to strengthen policy support for STEM-based education.

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Utilizing Narrative Literacy as A Language Learning Strategy: A Case Study on Multilingual Students

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ABSTRACT: Narrative literacy has been recognized as a key element in the development of language and literacy skills, particularly for multilingual students. This study explores the role of narrative literacy, using stories as a language learning strategy, for multilingual students. Employing a qualitative case study approach, data were gathered through interviews, observations, and document analysis at the State Islamic Senior High School Insan Cendekia (MAN IC) in Indonesia, which served a diverse multilingual population. The participants included both teachers and students. Findings suggest that narrative literacy significantly enhances students' language comprehension and skills. By engaging with narratives, students not only expand their vocabulary and grasp of language structures but also deepen their cultural and emotional awareness. Multilingual learners are particularly able to enrich their linguistic capabilities by integrating personal experiences relevant to their unique contexts and cultures. For educators, implementing narrative-based strategies presents both challenges and opportunities, underscoring their crucial role in fostering effective language learning in multilingual and multicultural settings.

Keywords: Literacy, Narrative, Language Learning, Multilingual, Multicultural

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INTRODUCTION

Narrative literacy has been recognized as a key element in the development of language and literacy skills, particularly for multilingual students (Zaimatun, 2023). Research indicates that narrative-based interventions can enhance both narrative production and comprehension skills among monolingual and bilingual learners. For instance, the Supporting Knowledge in Language and Literacy (SKILL) program has proven effective in improving narrative and reading skills in students at risk of language and literacy difficulties, regardless of their linguistic background.

Language exposure plays a crucial role in shaping oral narrative skills in bilingual students. A study on oral narrative abilities in French-English bilingual learners found that while one language may dominate in certain microstructural aspects, performance in other areas may be stronger in a different language (Cohen et al., 2021). These findings highlight the complexity of language learning and underscore the importance of diverse activities to ensure students can effectively process and produce language.

Research also reveals that multilingual students often rely on their various languages when creating narrative texts in a third language (Boksay Pap, 2016). A study involving Hungarian-Romanian bilingual students in Transylvania found that their first language was primarily used for task identification and self-regulation, while the second language served as linguistic support in crafting content in the target language. Narrative skills also significantly impact literacy development in bilingual children. A study assessing narrative skills in Spanish-English bilingual children discovered that while many showed improvement in English narrative skills, some performed worse in narrative recall tasks compared to spontaneous narrative production in one of their languages. This emphasizes the need for narrative assessments in both languages to gain a comprehensive understanding of bilingual competence.

The multilingual narrative approach also has a substantial impact on teachers' literacy pedagogy. A case study on primary school teachers using a multilingual narrative approach showed that sharing linguistic narratives in the classroom could reshape classroom dynamics and create space for validating linguistic diversity (Weidl et al., 2023). Such interventions play a vital role in shifting attitudes and teaching students to appreciate differences. In the context of the 21st century, language proficiency has become one of the most essential competencies, particularly for students in multilingual environments. Indonesia, as a country with remarkable linguistic diversity, faces significant challenges in language education. According to the National Language Agency, Indonesia is home to over 700 regional languages spread across the archipelago. This condition demands that students, especially those studying in madrasahs, acquire proficiency in the Indonesian language, foreign languages such as English, and religious languages like Arabic. However, without a well-structured learning strategy, the linguistic potential of multilingual students may not be optimally developed (Bailey et al., 2023). Additionally, globalization and digitalization have influenced how students perceive language and culture. A survey conducted by the Ministry of Education, Culture, Research, and Technology revealed that the cultural literacy levels of Indonesian students need improvement, particularly in their ability to understand cultural values through narrative-based texts. Narrative literacy approaches can serve as an effective solution for enhancing language skills while deepening students' cultural understanding. For madrasahs with multilingual students, this method offers an opportunity to strengthen students' language mastery in both local and global contexts (Yang, 2023).

The narrative literacy approach has long been recognized as an effective language learning method, especially in multilingual student environments. Research by Yaman, et al showed that using stories as a teaching tool can comprehensively improve language skills, including vocabulary, language structure, and cultural context

comprehension. Furthermore, narratives help students develop critical and creative thinking skills (Yaman et al., 2023). Meanwhile, another study by Hong & Cai indicated that narrative-based strategies are highly relevant in multilingual educational settings as they allow students to connect their linguistic experiences with cultural backgrounds and personal contexts (Hong & Cai, 2023). However, several challenges have been identified in implementing this strategy. For example, Siregar et al noted that teachers often struggle to develop narrative materials that are relevant to local culture (Siregar et al., 2022). Additionally, limited curriculum time frequently hinders the integration of narratives into lessons. Therefore, more systematic and contextually relevant strategies are required to optimize the effectiveness of this approach in madrasah settings.

This research is highly relevant in addressing language learning challenges in multilingual student environments. Narrative literacy not only aids students in improving their linguistic abilities but also broadens their understanding of cultural and emotional aspects. In this dynamic era of globalization, such skills are essential for students to compete globally. Furthermore, this study contributes by providing guidance for teachers in designing narrative learning strategies that are relevant to local culture while supporting multicultural settings. The research aims to offer an effective learning model for Madrasah Aliyah Negeri (MAN IC) in Indonesia by integrating narrative literacy into the curriculum. Through this approach, multilingual students will not only enhance their linguistic competencies but also gain deeper insights into local and global cultural values. Additionally, the study seeks to help teachers overcome challenges in implementing narrative literacy, thereby creating an inclusive, relevant, and meaningful learning environment for students in the current era.

Several studies relevant to this research are as follows: The study by Hong & cai titled *Evidence-Based Educational Practices for Working With Refugee Children.* The Use of Narrative Literacy for Developing Multilingual Students' Language Skills indicates that narrative literacy can enrich vocabulary and improve language skills among multilingual students (Hong & Cai, 2023). While both studies examine narrative literacy as an approach to language learning, this research emphasizes the development of language skills rather than the cultural understanding highlighted in the proposed study. Research by Tenzek et al about study *Integrating Narrative Literacy in Multilingual Education in Schools*, found that narratives can be integrated into language curricula to enhance multilingual students' language skills and cultural understanding (Tenzek et al., 2023). This study is similar in discussing narrative literacy but focuses more on its application in formal curricula, compared to the more in-depth case study approach in madrasahs taken by the proposed research.

The research by Jiang titled Effects of narrative persuasion in promoting influenza vaccination in Hong Kong: A randomized controlled trial. Narrative literacy can improve multilingual students' language competence (Jiang, 2021). While this research overlaps in its primary topic, it emphasizes language competency enhancement, whereas the proposed study combines language improvement with cultural understanding. The study by Lee, Y titled Narrative Literacy as a Tool to Enhance Cultural Understanding in Language Learning at Madrasahs, reveals that narrative literacy can enrich cultural understanding among madrasah students (Leyva et al., 2022). This research shares a common focus on narrative literacy in madrasahs, but the proposed study covers a

broader cultural context compared to this study's emphasis on religious values.

Research by Alexander titled The Role of Narrative Literacy in Supporting Multilingual Education: A Case Study of Secondary Schools, examines the role of narrative literacy in supporting multilingual education at secondary school levels (Alexander, 2023). Although it discusses multilingual education, this study focuses on teaching at general secondary schools, while the proposed research emphasizes education in madrasahs.

Most of the studies relevant to this topic examine narrative literacy as a language learning strategy for multilingual students. While there are similarities in the topics discussed, the main difference lies in the focus of the research. Some studies emphasize theoretical aspects and curriculum development, whereas the proposed research focuses more on case studies in madrasahs and their application within the cultural and emotional contexts of students.

This research contributes significant novelty to the field of language education, particularly in madrasahs, by utilizing narrative literacy as a teaching method. Some of the innovative aspects offered by this research include: Contextual Approach in Madrasahs: Most studies on narrative literacy are conducted in general schools or higher education institutions. This research focuses on madrasah aliyah, which has unique characteristics where students not only learn language as a means of communication but also as a way to understand religious and cultural values. The use of narrative literacy in this context creates new opportunities to link language learning with the reinforcement of cultural and religious values.

Case Study of Multilingual Students: This research highlights multilingual students, a group that often faces challenges in mastering languages. By utilizing narrative literacy, this study delves deeper into how stories related to students' cultural and personal experiences can enhance their understanding of the language being learned while enriching their language skills. Cultural and Emotional Understanding Through Stories: One of the novelties of this research is the integration of emotional and cultural aspects into language learning. Narratives are not only used to improve language proficiency but also to help students connect their personal experiences with the language being studied, fostering deeper understanding and developing students' emotional intelligence.
The state of the art in this research, particularly in the field of language education, focuses on narrative literacy within multilingual and multicultural education. It encompasses: Innovations in Multilingual Language Learning, Narrative Literacy as a Tool for Social- Emotional Development, Innovative Learning Models for Madrasahs, and Integrating Multilingual Perspectives with Narrative-Based Learning.

Method

This study employs a qualitative approach with a case study technique to describe how narrative literacy is applied as a language teaching method for multilingual students. This approach was chosen to deeply explore the experiences of teachers and students in using narrative literacy within the educational context of madrasahs.

Data is collected through three primary methods: in-depth interviews with teachers and students, direct classroom observations, and document analysis related to the implementation of language learning curricula at Madrasah Aliyah Negeri Insan Cendekia (MAN IC).

Interviews with teachers aim to understand the challenges and opportunities in implementing narrative literacy, while interviews with students seek to uncover how they connect stories with personal experiences in the language learning process. Classroom observations are conducted to record the use of narratives in teaching and the interactions among students during the learning process. Additionally, curriculum documents and teaching materials used by teachers will be analyzed to provide a clearer picture of how narrative literacy is implemented in this context.

To support this research, several instruments are required, including structured interview guidelines, observation sheets to document classroom dynamics, and curriculum documents and teaching materials. The collected data will be analyzed using thematic analysis techniques to identify and categorize key themes related to the impact of narrative literacy on students' language skills, as well as the challenges and strategies faced by teachers in the context of multilingual and multicultural education. This process aims to illustrate how narrative literacy contributes to improving students' language proficiency and how teachers adapt this method in a diverse educational environment.

Results and Discussion

Based on the analysis of data obtained through interviews, observations, and document studies, this research highlights several significant findings regarding the implementation of narrative literacy as a language learning strategy at Madrasah Aliyah Negeri Insan Cendekia (MAN IC), particularly for multilingual students, as follows:

Enhancement of Students' Language Skills through Narrative Literacy

This study found that the use of narrative literacy has a significant positive impact on students' language skills, particularly in speaking, writing, and understanding language structures. Interviews with teachers revealed that story-based learning helps students enrich their vocabulary. During the storytelling process, students are required to select appropriate words within the context of the story, which strengthens their vocabulary mastery. Moreover, narrative-based learning engages students, improving not only their language skills but also offering them an opportunity to understand how language is used in everyday life.

In addition to enriching vocabulary, narrative literacy facilitates students in comprehending grammar and sentence structures. Teachers explained that the use of stories allows students to see real-life examples of the grammatical rules they are learning, making it easier for them to understand and remember these rules. For instance, students found it easier to grasp the use of tenses or passive sentence structures when presented in the

form of stories, which are more comprehensible due to their clear context. This approach makes language learning more relevant and simplifies grammar mastery.

Students interviewed also expressed that they felt more confident and comfortable after learning through stories. They stated that using stories allowed them to express themselves more freely. The stories they created or heard were closely related to their personal experiences, making learning more enjoyable. Classroom observations indicated that students became more active in discussions and more willing to speak in front of the class. Narrative literacy provides a space for students to convey their ideas in a more natural language that resonates with their lives.

Additionally, findings showed that narrative literacy also contributes to the development of students' emotional skills. The stories they read or heard often reflect feelings, conflicts, or experiences that influence their emotions. By engaging in narrative-based learning, students became more capable of recognizing and expressing their emotions through the language they were learning. This makes language learning more meaningful and profound, as it incorporates emotional elements that help students better remember vocabulary and language structures.

Multilingual students from diverse linguistic backgrounds also benefited from the narrative-based approach. Although some initially struggled to follow the stories, their confidence grew over time. They were able to connect language learning to their own experiences, allowing them to naturally remember vocabulary and sentence structures. Narrative literacy not only develops language skills but also provides an inclusive and comprehensive learning context for students.

Strengthening Cultural and Emotional Understanding through Narratives

The study also revealed that narrative literacy strengthens students' cultural and emotional understanding. According to student interviews, they found it easier to grasp cultural values embedded in the stories. Stories provide an effective way for students to observe how customs, traditions, and ways of life within a culture influence language use. Students were able to identify cultural elements in the stories they studied, helping them expand their understanding of social and cultural differences around the world. Through stories, students gained deeper insights into social norms and communication practices across various cultures. Furthermore, narrative literacy plays a crucial role in enhancing students' emotional understanding. Students felt more connected to the characters in the stories as they could empathize with the emotions experienced by these characters. Through storytelling, students were able to identify and express their own emotions, enriching their ability to communicate emotionally. Language learning thus not only involves technical skills but also builds emotional connections with the material, motivating students and making them more prepared to learn.

Stories allow students to express their ideas and feelings more freely and openly. When students were asked to share their personal stories or narrate their experiences in the language being learned, they found it easier to

understand and use the language to describe their emotions. This helped students gain confidence in communicating, both in their first language and the second language they were learning. Hence, narrative literacy provides opportunities for students to develop essential social and emotional skills for interacting with others.

This process also fosters a sense of empathy among students, as they come to understand and relate to the experiences of others through storytelling. Narrative-based learning helps students appreciate cultural differences and view the world from others' perspectives. This understanding enriches their social and communication experiences both inside and outside the classroom. Learning involving storytelling equips students with vital social skills, such as the ability to empathize, listen attentively, and share feelings.

Narrative literacy also introduces students to a deeper understanding of the interconnectedness between language and culture. Narrative-based learning offers students opportunities to develop language skills within a holistic context, where language serves not only as a communication tool but also as a medium for understanding the world and human relationships. This type of learning helps students become more engaged and appreciate the role of language in everyday life.

Challenges in Implementing Narrative Literacy in Multilingual Learning

One of the main challenges in implementing narrative literacy in multilingual classrooms is the varying levels of language proficiency among students. Based on interviews with teachers, they revealed that applying narrative literacy can sometimes be difficult to implement uniformly, as students have diverse language abilities. Students with stronger language skills can follow the flow of the stories and actively participate in class discussions, while those with weaker skills often struggle to understand the stories and contribute to the learning process. This creates an imbalance in classroom dynamics, requiring adjustments in teaching methods and materials to accommodate all levels of student language proficiency.

Time constraints also pose a significant issue in the application of narrative literacy. Teachers reported that the tight schedule often forces them to focus on more technical aspects of language learning, such as grammar and vocabulary, which are often prioritized for instruction. With limited time, it becomes challenging to provide adequate opportunities for students to engage deeply with the stories and connect them with their personal experiences. This also affects the teachers' ability to give individualized attention to each student, especially those who need more time to grasp the material.

Nevertheless, despite these challenges, many teachers attempt to address the issues by assigning narrative-based tasks outside the classroom, such as writing stories or listening to narratives as homework. This strategy allows students to remain engaged with storytelling even with the limited classroom time. Teachers also strive to align the story materials with the students' language proficiency levels, ensuring that every student can benefit from narrative-based learning.

Some teachers also suggested implementing narrative literacy gradually, starting with simpler stories and progressively transitioning to more complex ones. This approach enables students to improve their understanding of stories over time without feeling overwhelmed by narratives that are too intricate. This gradual method allows students to follow the learning progression, which supports the development of their language skills in a structured manner.

Despite these significant challenges, teachers agreed that narrative literacy remains a highly effective strategy for enhancing students' overall language skills. These challenges also provide opportunities for teachers to innovate in their teaching methods, developing more varied and inclusive teaching materials that benefit all students, ensuring that every individual can maximize the advantages of a narrative-based approach.

This study found that narrative literacy plays an important role in improving students' language abilities, not only in terms of vocabulary and sentence structure acquisition but also in developing speaking and writing skills. Through stories, students can deepen their understanding of language while exploring the cultural and emotional meanings embedded within them. Although there are challenges related to language proficiency differences and time constraints in learning, the results indicate that a narrative-based approach remains effective when applied appropriately.

The findings of this study highlight the positive impact of narrative literacy, as story- based learning integrates cognitive, social, and emotional elements. Stories enable students to connect the language they are learning with their real-life experiences, making it more relevant and easier to understand. Narratives provide space for students to express their emotions, strengthen their language comprehension through familiar contexts, and enhance their engagement in the learning process. The social and cultural aspects of stories also help students broaden their perspectives on the world.

The interpretation of these findings suggests that narrative literacy is not merely a language teaching method focused on technical skills but also introduces students to enriching social and emotional experiences that enhance their language mastery. Stories allow students to express and explore their thoughts and emotions more freely, improving their communication skills in a deeper context. Therefore, narrative literacy can help students develop holistically by integrating cognitive, emotional, and social aspects into language learning.

These findings imply that integrating narrative literacy into the language learning curriculum can enrich students' learning experiences. Story-based language learning not only helps students acquire technical language skills but also shapes a broader understanding of culture and social relationships. This underscores the need for a more inclusive and adaptive approach in curriculum design, where teachers are trained to implement narrative methods tailored to students' needs and language proficiency levels.

This research aligns with several prior studies that have demonstrated the effectiveness of narrative literacy in improving language skills and cultural understanding. For instance, studies by Muthiah et al and Leyva et al that

highlight the importance of narratives in enriching vocabulary and understanding language structures.(Muthiah et al., 2021) (Leyva et al., 2022) However, this study focuses more specifically on multilingual contexts and provides additional insights into how narrative literacy helps multilingual students connect their personal experiences to the language they are learning. Compared to earlier research, this study delves deeper into the emotional aspects of narrative literacy, showing that stories are not only tools for teaching language but also for helping students manage and express their emotions. These findings introduce a new dimension to language learning development, which has not been extensively explored in previous literature.

Based on the findings of this study, several steps can be taken to enhance the integration of narrative literacy into language learning. Developing and designing a language curriculum that incorporates narrative literacy as a central component in the teaching-learning process is essential. Teachers need to be engaged in training programs to utilize stories effectively in various forms, both oral and written, for multilingual classrooms. Additionally, learning materials should be tailored to students' language proficiency levels and should consider the cultural diversity within the classroom. The goal of these action plans is to create a more inclusive and responsive learning environment that addresses the needs of all students, ensuring that narrative literacy can be optimally implemented to improve their language skills.

Conclusions

The findings of this study reveal a surprising insight: story-based learning not only enriches language comprehension but also provides students with an opportunity to better understand the cultural and emotional contexts embedded in stories. This demonstrates that language learning through narratives can help students connect the language they are studying with their personal experiences, making the learning process more relevant and meaningful. The primary contribution of this research lies in the concept of integrating narrative literacy into language learning within multilingual environments, such as at Madrasah Aliyah Negeri Insan Cendekia (MAN IC) in Indonesia. This concept introduces a new approach to language teaching that not only emphasizes technical language mastery but also fosters the social and emotional development of students. Methodologically, this study employs a qualitative approach and case study design, which provides a deeper understanding of how narrative literacy is implemented in multilingual classrooms. This contributes to the development of more inclusive and adaptive language learning theories. However, the study has a limitation in that it does not fully explore the challenges students face in understanding and accessing stories in a language they have not yet fully mastered. Therefore, future research is recommended to delve deeper into the factors that influence the effectiveness of narrative literacy in language learning.

Acknowledgments

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An Analysis of Research Studies on the Use of Digital Storytelling in Preschool Education in Türkiye

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Abstract: As technology has become increasingly integrated into every aspect of our lives, the concept of storytelling has transformed into the practice of "digital storytelling", the process of presenting stories to viewers by organizing them in digital environments by including multimedia elements such as pictures, music, movement and video. Within the context of technology integration in education, digital storytelling can be potentially used to enhance teaching and learning especially in preschool children. It is important to investigate this potential scientifically and transfer findings to practitioners in schools. Therefore, this study aims to examine research studies on the application of digital storytelling in preschool education. It was designed as a descriptive study using document analysis to collect and analyze the data. Using appropriate keywords, a literature review was conducted on the digital databases of academic studies and 10 study conducted in Türkiye and published between 2011 and 2021 were selected. Then, they were thoroughly read and annotated bibliographies were created using information such as authors, publishing year, research purpose or questions, methods and materials, and salient findings. The findings included these annotations and frequency distributions for some research attributes such as year, research design, data collection tool, implementation process, and variables employed.

Keywords: Digital storytelling, Preschool education, Literature review, Document analysis

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Introduction

As technology becomes more deeply embedded in daily life and education (Kibici, 2022a, 2022b, 2025; Kilincer, 2021; Ozdemir, 2022; Ozkan, 2022; Ozturk & Ozturk, 2022, 2024; Tekin, 2025), traditional storytelling has evolved into "digital storytelling," a practice in which narratives are crafted and shared in digital environments using multimedia elements such as images, music, animation, and video. The phrase of digital

storytelling in composed of the concepts of digital and storytelling. The latter means sharing narratives and experiences with others through traditional media such as novels. Incorporating the former with this means bringing in the use of multimedia tools (e.g., text, image, audio, and video) and social media. There are a few definitions of digital storytelling in the related literature.

Ohler (2008) defines it as a creative process that combines a traditional story with personal digital technologies such as computers, video cameras, and audio recorders. For Chung (2007), it is a multimedia presentation application that includes digital text, images, video and audio in a computer environment. Yüksel, Robin and McNeil (2011) describe it as sharing information and telling stories through multimedia tools and resources. According to the Digital Storytelling Association (2002), it is a modern expression of the ancient art of storytelling. Although there are many definitions of it as such, the common and basic idea in these definitions is that digital storytelling is about using digital technologies to tell stories.

Although there are variety of digital stories, Robin (2008) gathered them under three groups as: personal narratives, informational or instructional stories, and historical stories. The first one contains telling lived experiences meaningful to both the author and the viewer including memory of specific people and places, life's adventures, accomplishments, challenges, and recovery. The second one conveys information to learners in many different content areas (e.g., demonstrating how to use a camcorder, calculate what can be done to increase someone's health during the aging process and how to help students understand principles of geometry). The third one focuses on recounting events from the past in a way that makes listeners feel like they are experiencing (Robin, 2008).

Digital storytelling first emerged in the 1990s with the work of Joe Lambert and her team in California. Lambert (2003) identified seven element of digital storytelling, which can be considered as a general guide for the creation of digital stories:

- Point of view: What is the main point of the story and what is the perspective of the author?
- Dramatic question: A key question that keeps the viewer's attention and will be answered during the story.
- Emotional content: Serious issues that allows viewers to establish a strong emotional bond with the story.
- Voice: The author adds sound to her story or narrates it in order to personalize the story.
- Music: Use of background audio compatible with the story.
- Economy: Presentation of content to the viewers without overloading them.
- Pacing: Adjustment of how slowly or quickly the story progresses.

Some scholars have developed various processes of digital stories and their stages do not differ much from each other. The process has a hierarchical structure beginning with story creation and ending with the sharing of it. Tolisano (2008) defined three stages: preparation, production and presentation. The preparation stage comprises writing a scenario that suits the theme and message of the story, creating storyboard that organizes the flow of the story and then preparing the narration. The production stage involves finding or developing multimedia

elements, merging multimedia and narrative elements according to storyboard to create the story, and obtaining peer opinions from a small group (i.e., pilot testing). The presentation stage includes sharing the story with the target audience in classroom, computing or social media environments through computer, phone, tablet, projector, internet etc. (Tolisano, 2008).

Storytelling has been used primarily in educational activities for centuries as a method of transferring knowledge and experiences because stories are interesting and attention-grabbing. As technology has become increasingly integrated into every aspect of our lives, the concept of storytelling has transformed into the practice of "digital storytelling. Within the context of technology integration in education, digital storytelling can be potentially used to enhance teaching and learning especially in preschool children. It is important to investigate this potential scientifically and transfer findings to practitioners in schools. Therefore, this study aims to analyze prior research conducted in Türkiye on the use of digital storytelling in early childhood education in order to (a) explore the potential of digital storytelling for child development, (b) reflect on how to integrate it into preschool teaching process, (c) get familiar with the current research practices and trends and (d) make implications for future research in this field.

Method

This study was designed as a descriptive survey research with document analysis as a data collection tool. Document analysis refers to the analysis of written materials containing information about the subject under investigation (Yıldırım & Şimşek, 2011). Data collection and analysis were done in two stages. In the first stage, the researchers conducted a literature review of journal articles and graduate theses completed in Türkiye and published in Turkish language in the last 15 years (2011-2025). Thus, an attempt was made to access research studies on digital storytelling in the preschool period in Türkiye.

Relevant studies were accessed through the search engines by Google Scholar and National Thesis Center operated by the Turkish Council of Higher Education (YÖK) using searching keywords like "digital story", "digital storytelling", "preschool", "kindergarten", "early childhood" to reach appropriate studies. This center collects theses conducted in Turkish universities as an online database and makes them accessible to users via a search engine (YÖK, 2025). To be included or excluded in the study, search results were filtered by taking into consideration criteria such as using the digital storytelling method, including application examples, and being applied to preschool students.

In the second stage of the data analysis, the studies selected from the literature search in the first stage were subjected to three-step content analysis process. First of all, both abstracts and full texts of the studies were carefully scanned and read to get familiar with the research carried on in the studies. Next, the researchers created annotated summaries of the studies containing research questions, method, sample, data, and results. Lastly, the studies were categorized in accordance with the research purpose under major themes. In addition to these summaries, a digital spreadsheet was created including data such as who conducted the study, when it was

conducted, targeted population, sample size, focused variables, data collection methods, digital tools used for storytelling, type of stories, and children's role in the use of digital stories.

Results

After careful searching and inspecting the related literature, the researchers decided that a total of 13 studies were appropriate with the selection criteria and thus included in the review. As can be seen from the Figure 1, most of them were journal articles (61.54%) while only one of them (7.69%) was a doctoral dissertation. There were 4 studies (30.77%) submitted for the completion of master's degree.

Figure 2 shows the distribution of studies according to the years they were published or completed. On average, there was at least one study per year, with a jump seen in especially 2017 and 2019. One can also say that the number of studies tends to decrease over the years.

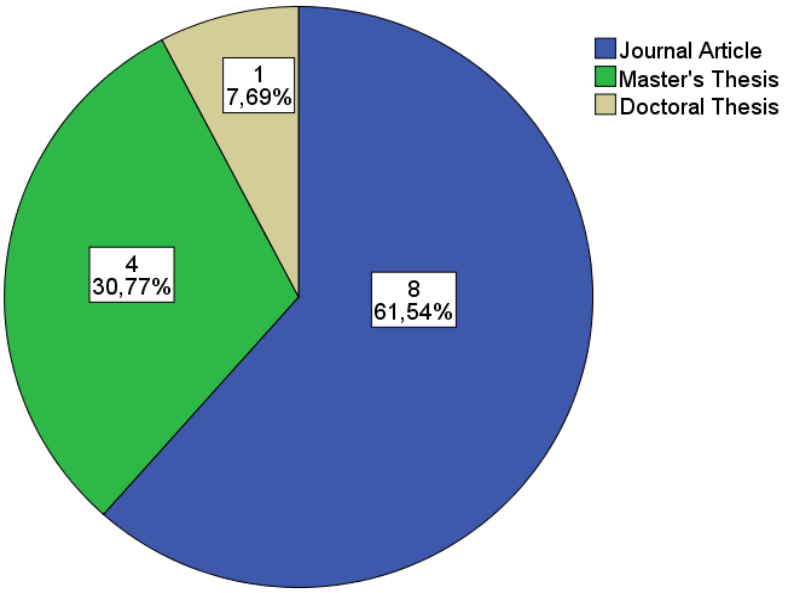

Figure 1. Studies Included in the Review

As far as research methods that the reviewed studies employed were concerned (Figure 3), more than half (53.85%) used experimental research design (e.g., pretest posttest experiment with control, posttest only experiment with control), followed by qualitative (15.38%) (e.g., case study, document analysis) and mixed method designs (15.38%). Moreover, there was one study utilizing design-based and one using longitudinal research method.

Regarding their targeted population (Figure 4), majority of the studies were conducted with 4-6 aged preschool students (85%) being the research participants. A few studies were conducted with preschool teachers (15%) or digital stories (8%).

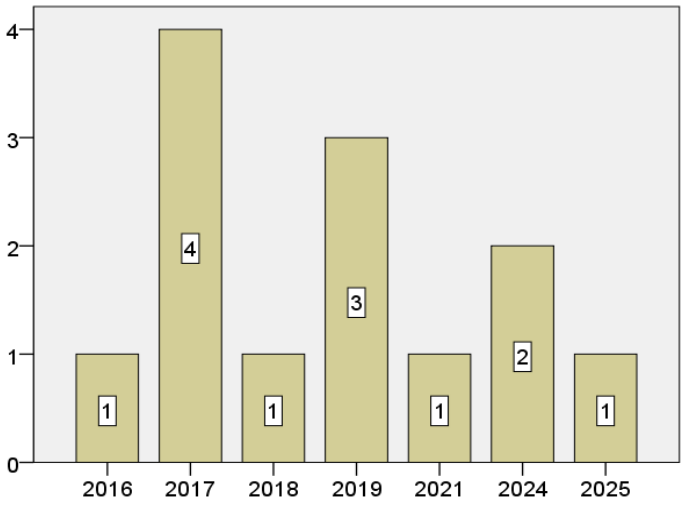

Figure 2. Years of Studies Reviewed

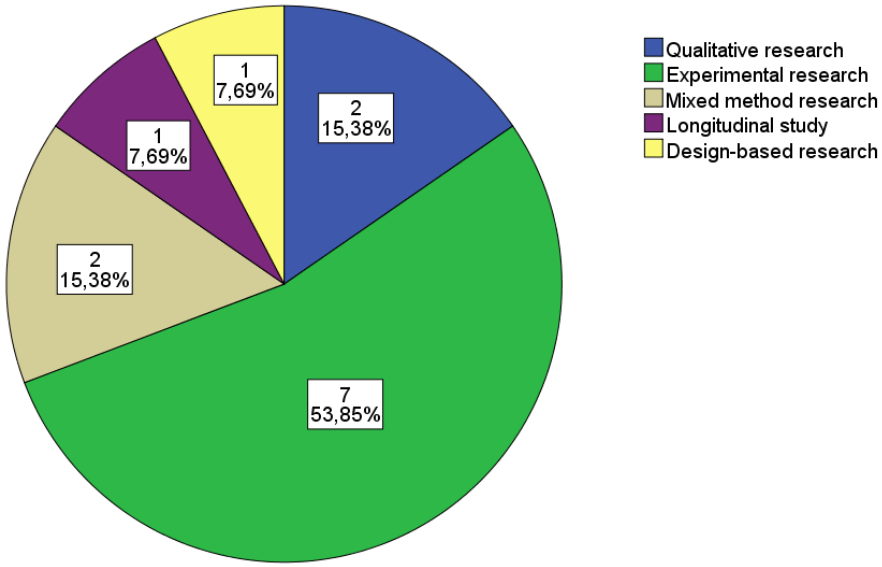

Figure 3. Research Methods Employed in the Studies

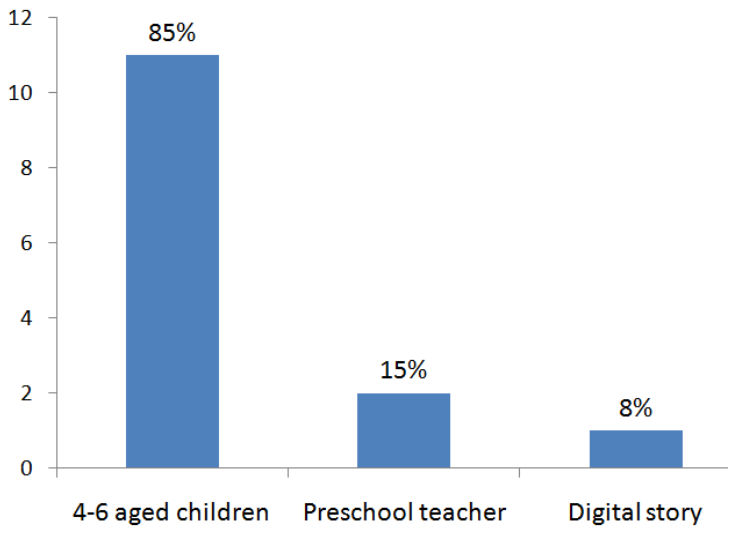

Figure 4. Target Population of Studies Reviewed

Figure 5 presents the distribution of sample sizes employed in the studies. Generally speaking, they preferred small sample sizes as all of them were conducted with one hundred or fewer participants. Almost 40% of the studies were conducted with 26-50 participants, the same amount of studies being carried out with 51-75 participants, two studies being conducted with 1-25 participants and one study being conducted with 76-100 participants.

The studies were pretty eclectic in terms of the variables investigated as they examined a number of variables as shown in Figure 6 including comprehension (23%), social-emotional behaviors (23%), listening skills (15%), word learning (8%), visual language skills (8%), value development (8%), gender equality (8%), environmental attitude (8%), digital story use competency (8%),, educational needs (8%), and opinion (8%) with comprehension and social-emotional behaviors being the most researched variables.

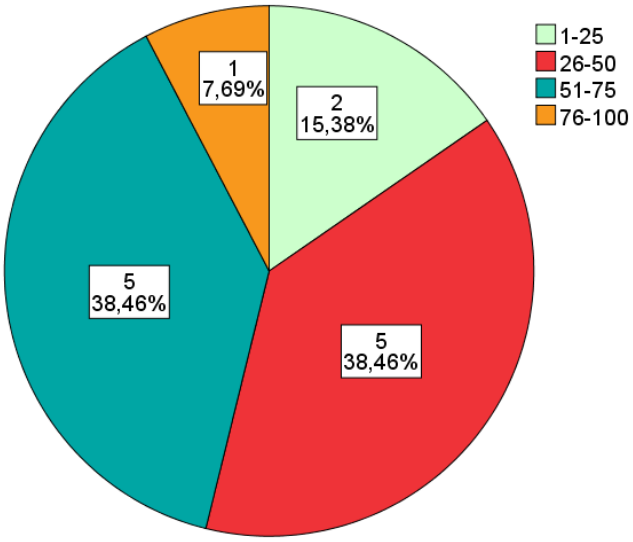

Figure 5. Sample Sizes Preferred in the Studies Reviewed

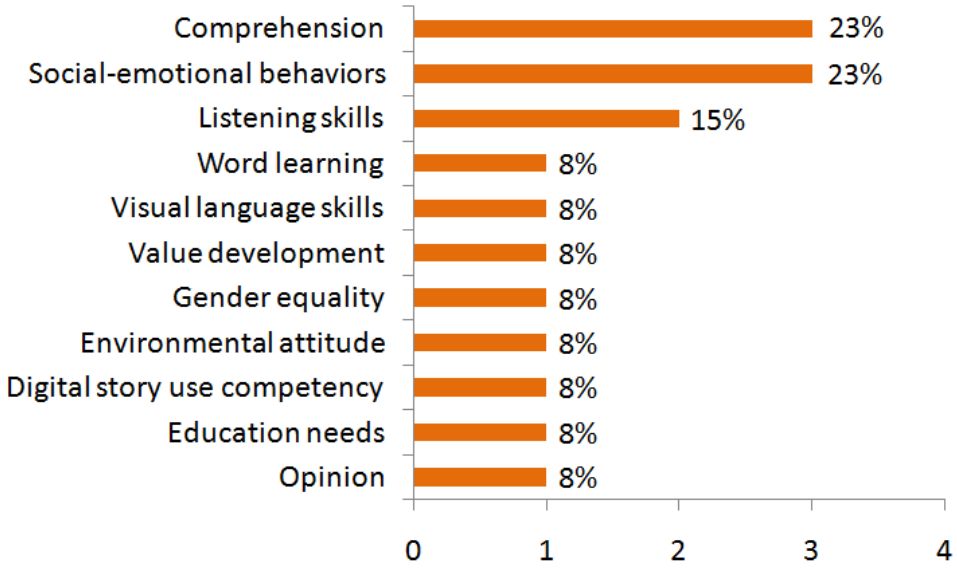

Figure 6. Variables Examined in the Studies Reviewed

Table 1 summarizes the data collection tools used in the studies and their purpose of usage. Scales or tests were the most frequently used data collection tools to measure the variables (54%). Example tools in this category included Story Comprehension Test, Peabody Picture Vocabulary Test, Sentence Repetition Tasks, Social Skills Assessment Scale, and Preschool Values Scale. They were often used to measure the dependent variables in the experimental research. In almost one third of the studies (31%), observations were conducted to record children's digital story making or listening activities. Some studies utilized semi-structured interviews (23%) or anecdotal notes (8%) to gather teacher opinions and experiences about the integration of digital storytelling in preschool education.

Table 1. Data Collection Tools Employed in the Studies Reviewed

Tool (%)	Purpose
Scale or test (54%)	To measure the dependent variables of the study
Observation (31%)	To observe children's process of creating and/or listening digital stories in terms of behavior/skills change
Interview (23%)	To gather teacher opinions and experiences about the use of digital storytelling activities with children or to assess children's listening skills
Anecdotal notes (8%)	To collect teachers' explanations about what and how digital storytelling activities work or fail (successes and errors)
Document analysis (8%)	To analyze the content and scope of the digital stories

Figure 7 shows the distribution of digital apps used for digital storytelling activities in the studies. As can be seen in the figure, the studies were not picky about the apps as they employed various tools including Movie Maker (15%), PhotoStory (15%), My Storybook (8%), Pixton (8%), StoryJumper (8%), and StoryBird (8%).

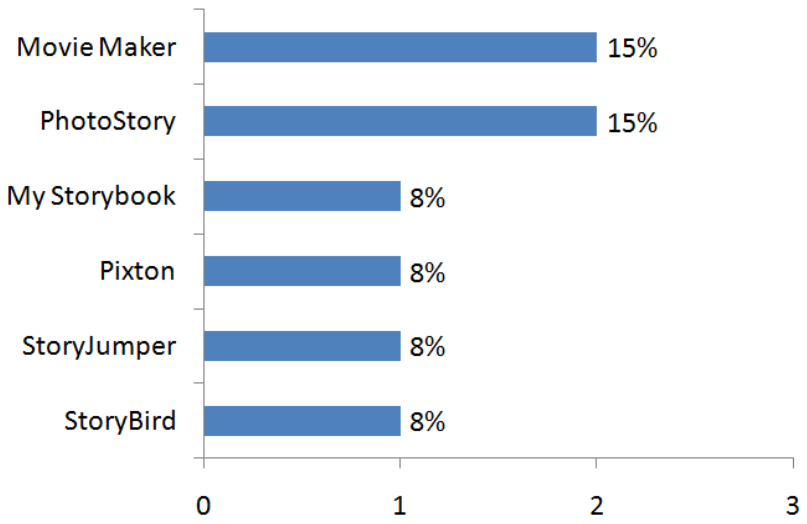

Figure 7. Digital Apps Used for Digital Storytelling in the Studies Reviewed

The researchers also coded the type of digital stories using the descriptive information provided in the studies

and the findings were shown in the Figure 8. The majority of the studies employed informational or instructional type of digital stories. Only one used personal type whereas there were no studies using historical type digital story.

Studies were also inspected in terms of the role given to children as participants of the research. As illustrated in Figure 9, in more than half (54%), children listened or viewed digital stories that have been already created by others. However, in the remaining (38%) they actually created stories.

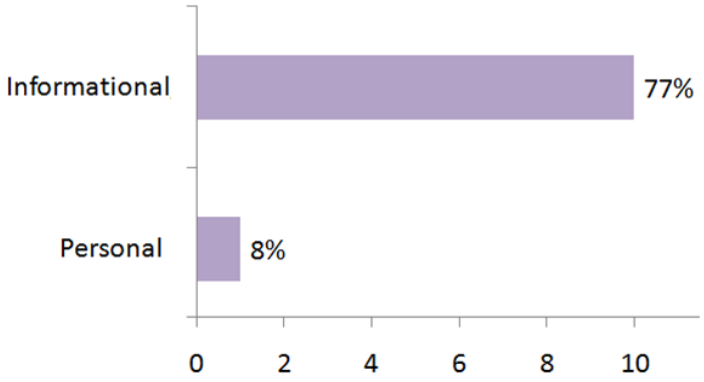

Figure 8. Type of Digital Stories Used in the Studies Reviewed

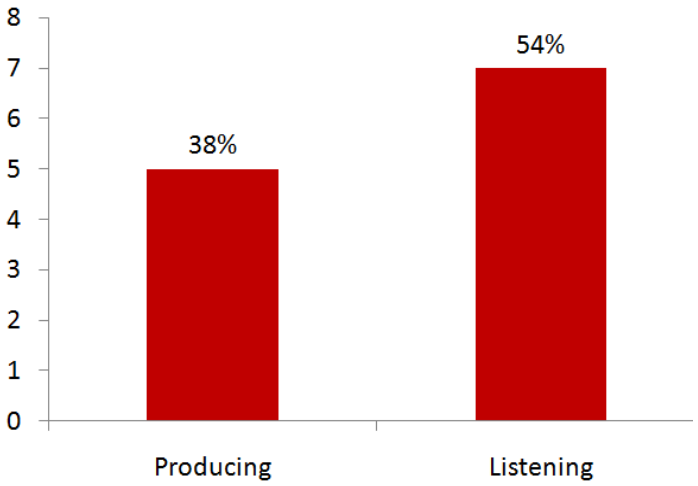

Figure 9. Children's Role in Studies Reviewed

The researchers categorized studies according to their research problems and purposes in three groups. In the first group, there were nine studies (69%) investigating the effect of using digital storytelling on children variables. These studies were called as outcome-oriented studies. They typically compared digital storytelling activities with traditional ones or compared digital stories with different formats (animations, music, voice etc.) in terms of various dependent variables. All studies reported positive effect on such variables as controlling anger behavior, abilities of adapting to changes, coping with peer pressure, verbal description skills, listening skills, completing tasks skills, environmental awareness and attitude, teachers' competence in using digital

stories, friendship, cooperation and responsibility values, word learning, and story understanding. Three of these revealed no effect interpersonal skills, self-control skills, skills to accept results, respect, honesty and sharing values. Only one study revealed negative effect of digital stories with background music on word learning

The second group comprised 3 studies exploring children's or teachers' lived experiences during digital storytelling activities. These studies were called as process-oriented studies. They describe teachers' opinions or reflections about children's behaviors after participating in digital storytelling activities. According to their findings, participating teachers think that digital storytelling attracts the attention and interest of children, offers a fun learning experience, ensures active participation of children, supports digital technology literacy, improves children's creative and critical thinking, contributes to social-emotional behavior change, adapts children to different contexts and provides children with effective visual communication process. On the other hand, in one study teachers think that they lack of theoretical and technological knowledge and are concerned about difficulty or inefficiency in crowded classes.

The third group included only one study examining content and scope of digital stories. It was called as content-oriented study. It analyzed a number of digital stories broadcasting for children in Electronic Library of the Turkish Radio and Television Corporation (TRT) in terms of sensitivity to gender equality. Its findings showed that men were more prominent than women in terms of characters, occupations and accessories represented in the stories.

Discussion and Conclusion

After reviewing the content of studies, the researchers reached some main conclusions. Studies on digital storytelling in preschool education are less than those in primary and secondary education. This suggests that using digital stories is more preferable in older students who are already capable of writing and reading. I can be inferred that digital storytelling seems to be losing its popularity in the literature as the number of studies has been falling throughout the years. One reason for this may be the increasing popularity of shorts, a type of short-form video content (about 60 seconds or less) created on a mobile device and uploaded directly to social media platforms (e.g., YouTube TikTok). Shorts provide variation, convenience and entertainment. Using touch-screen mobile devices, preschool children are able to access online platforms to watch these short videos.

The studies reviewed in this study were designed by mostly quantitative research approaches and statistical data analyses. The majority of research evidence belonged to the population of preschool children and gathered from small samples. It can be said that the benefits of digital storytelling for children have been over-researched. However, enabling and inhibiting factors for its successful integration in preschool classroom have been less-evidenced. The findings suggest that preschool teachers can use digital storytelling as a pedagogical tool to support various aspects of child development as digital storytelling has important implications for children's progress from consuming media to producing media.

Based on the findings of this study, several suggestions can be made for future researchers in this field. The decreasing number of studies on digital storytelling can be investigated to explore its underlying reasons. Is it losing its attractiveness? Is it replaced with something? A variety of qualitative research methods can be employed for better and detailed understanding of the potential of digital storytelling on preschool education. More studies can be conducted on preschool teachers to explore their actual experiences of its integration into their teaching. Future studies can focus on investigating different aspects of digital storytelling (e.g., enables or barriers to its integration) rather than its effect on some variables.

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Methodological Illustrations of Way Forward to A Cumulative Psychological Science in Academic Help-Seeking Behavior of College Students

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Abstract: Li et al. (2023) reported a comprehensive systematic review of academic help-seeking behavior of college students. Their review included studies from nearly twenty countries, although most of them were from the United States of America. Five broad themes were identified characterizing students' help-seeking behaviors, including 1) definitions, theories, types and processes of the behavior, 2) the relationship of help-seeking and performance, 3) resource types, locations, and frequencies, 4) positive, negative, and irrelevant factors in help-seeking behavior, and 5) characteristics of online help-seeking behaviors. These culminated in recommendations for four areas of future research. The four areas included the nature of, resources for, factors affecting, and methodologies deployed to study, academic help-seeking behaviors of college students. The present study applies to these future directions the guidelines outlined by Imam (2024) for moving psychology toward achieving a cumulative science as illustrations. Each case illustrates how the research cycle operates differently from the standard research practices commonly deployed in mainstream psychology today..

Keywords: Psychology, Methodology, Process Method Approach, Cumulative Science, Academic Help-Seeking

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Introduction

Dichotomous thinking associated with significance testing has derailed the goal of achieving a cumulative psychological science (Amrhein, Korner-Nievergelt, & Roth, 2017; Branch, 2014; Kruschke, & Liddell, 2018b) since the widespread adoption of null hypothesis statistical testing (NHST) about the middle of the twentieth century (Hubbard & Ryan, 2000; Imam, 2021, 2024). The problematic side effects of the blanket reliance on NHST have been widely acknowledged and condemned, but its use has been hardly eschewed sufficiently to warrant a respite from serious concerns about the state of psychological science. Psychological researchers continue to reply on 'significant' and 'not significant' decision making regarding their data based on *p*-value reporting, despite the recognition that the *p*-value is no more than a bet against chance (see Trafimow et al.,

2018; Nuzzo, 2014). Habits are hard to break but the problem is multiplied with the mass ritualization of NHST in psychological research. As Imam (2024) put it,

> The myriad of problems that ensued due to the ritualized use of NHST in mainstream psychology were unavoidable and intractable. Multiple statistical assumptions in psychological research are routinely violated (Erceg-Hurn & Mirosevich, 2008). One questionable research practice (QRP) begot another and all became routine. For example, incentivized pursuit of the "sexy," such as happened in the power posing saga (Whitt et al., 2022), encouraged *p*-hacking, a practice that invariably builds a literature wrought with publication bias. Heavy reliance on college students from mostly western origins (Henrich et al., 2010; Krypotpos et al., 2022; e.g., Muthukrishna et al., 2020) for samples have raised questions of representativeness and generalizability of psychological phenomena. The charge of underpowered research while using group designs in psychology premised on the statistical requirement for large numbers often suggest use of power analysis (e.g., Wilson et al., 2022), which invariably also contributes to publication bias to the extent that sufficiently high power produces lower *p*-values and hence significant findings (Krypotpos et al., 2022; Wagenmakers, 2007) that then got published (p. 100).

A presenting problem is that most of the solutions being put forward have been mostly statistical in nature or tenor with the assumption that fixing statistical practices would fix the crisis of confidence that befell psychology due to the overreliance on NHST. The result has been neglect of other, nonstatistical solutions such as alternative methodological approaches.

Small-*N* designs have been used for decades in behavioral and vision research (Little & Smith, 2018; Sidman, 1960; Skinner, 1935; Smith & Little, 2018; see also Schwarzkopf & Huang, 2024). They center on in depth study of behavior of a few individuals, situations, or settings, each given considerable attention as each individual "serves as his or her own control, experiencing all conditions of the experiment. The analysis and reporting usually focus on revealed functional relationships between behavior and environmental conditions, emphasizing behavioral processes throughout. Moreover, they are known for their reputations in "'precise measurement, experimental control, and quantitatively exact theory' (Smith & Little, 2018, p. 2084)" (Imam, 2024, p. 99). Replications are built into the designs, variously across and within conditions, as with across participants and settings (Imam, 2021). Unlike in mainstream psychology, a failure to replicate in any such attempts does not amount to a doomsday but presents opportunities for reexamination of controlling variables in an experimental analysis (e.g., see Perone, 2019).

The contrasts between these two approaches in psychological research, in both processes and outcomes, motivated exploration of psychology's grand experiment described by Imam (2024). The recommended solution from the glaring results of that experiment, witness to the ongoing crisis of confidence in mainstream psychology bereft with replication failures uncommon in behavioral psychology, was an overhaul of psychology's modus operandum to reinvigorate the science toward the greater height of achieving a cumulative psychological science. Another area of distinction between mainstream and behavioral psychology is that the latter eschews hypothetical constructs (MacCorquodale & Meehl, 1948) whereas the former embraces them.

The problem is that they invariably become reified (see Holth, 2001), creating measurement problems in psychological scales (e.g., Maassen et al., 2023; see also Boring, 1961). Hence, Imam's (2024) retort: "There needs to be a shift from hypothetical constructs to greater focus on processes, individual as well as group processes (e.g., De Dreu & Gross, 2019)" (p. 104). Thus, the shakeup required for moving psychology forward toward a cumulative science mainstream psychology not only need to reassess its peculiar overrelaince on NHST but also its wholesale embrace of hypothetical constructs, in lieu of processes.

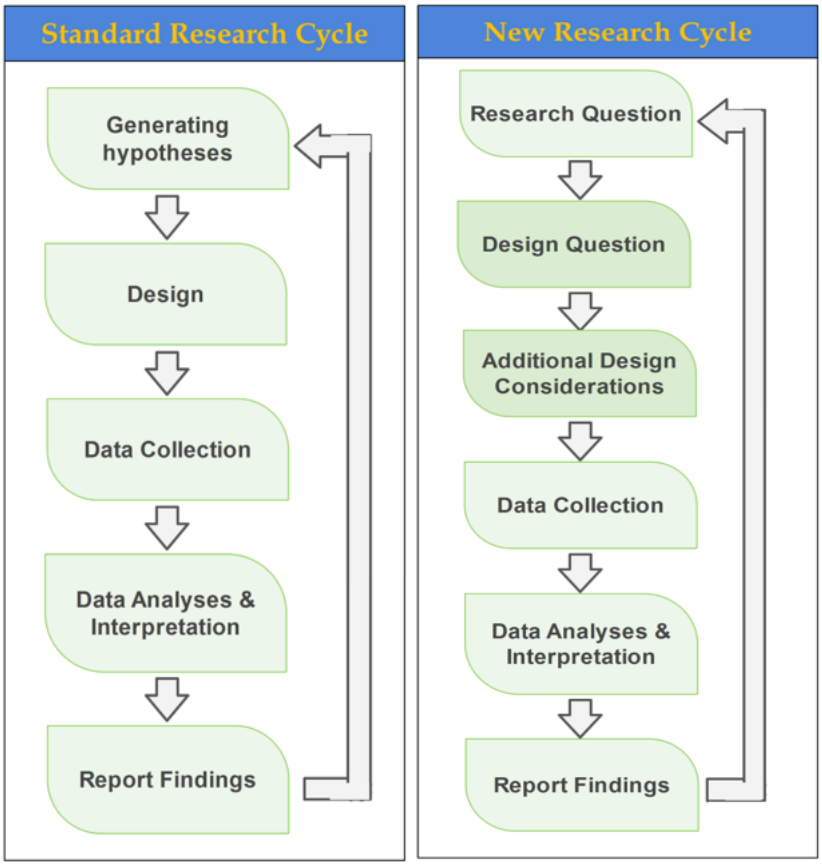

Figure 1. Standard (left) and new (right) research cycles illustrating the general steps for conducting large-*N* group designs in psychological research. See text for details.

Imam (2024) outlined the research cycle typically followed in conducting psychological research with large-*N* group designs. To reiterate here, the starting point (see Figure 1, left panel) is usually the formulation of a hypothesis pitting the null against some alternative that expresses the actual interest of the researcher. Based on statistical considerations, a design is adopted to include various manipulations of the independent variable(s), the basic version being a comparison of an experimental and a control group. Participants are then recruited and randomly assigned to groups for data collection. The data are then aggregated for analyses that are, more often than not, conducted using NHST. The results then are reported at conferences and eventually published, to be followed by new hypothesis to begin another cycle. There are multiple fault lines along this route. The initial formulation of hypothesis may or may not be informed by any specific theoretical position(s), typically, not. The participants recruited for the study tend to be predominantly college students who serve as convenient

samples. The aggregation of obtained data results in loss of individual performance or attributes. Development of theory is hardly of interest. Despite the commitment to NHST statistics in extant psychological research, violations of its assumptions and requirements are routine with predata collection neglect of statement of alpha and /or *p*-value, declaration of population of interest, unconfirmed normality requirements, missing power analyses (see Szucs & Ioannidis, 2017), neglect of random sampling, etc., etc. It is no wonder then that mainstream psychology has suffered enormous repercussions from its embrace of NHST to a fault.

Recognizing the historical availability of the small-*N* alternative that has largely avoided the pangs of such devastating rebuke of blind adherence to NHST, Imam (2024) recommended a new research cycle that differs from the standard by breaking from its first two steps and introducing three different conceptions of the steps (see Figure 1, right panel). Fundamentally, the research cycle begins with a research question as opposed to a hypothesis. The nature and tenor of the question then initiates a design question, rather than specify one informed by statistical considerations as is typically done. At this stage, the design question addresses whether the study should take an extensive (large-*N*) or an intensive (small-*N*) form (see Guilford & Dellenbach, 1925; Oberly, 1928) as dictated by the research question. Upon deciding on the use of an extensive study, the additional design considerations include determining the goal and interest in estimating population parameters (see Figure 2), which then would trigger inferential statistics matters.

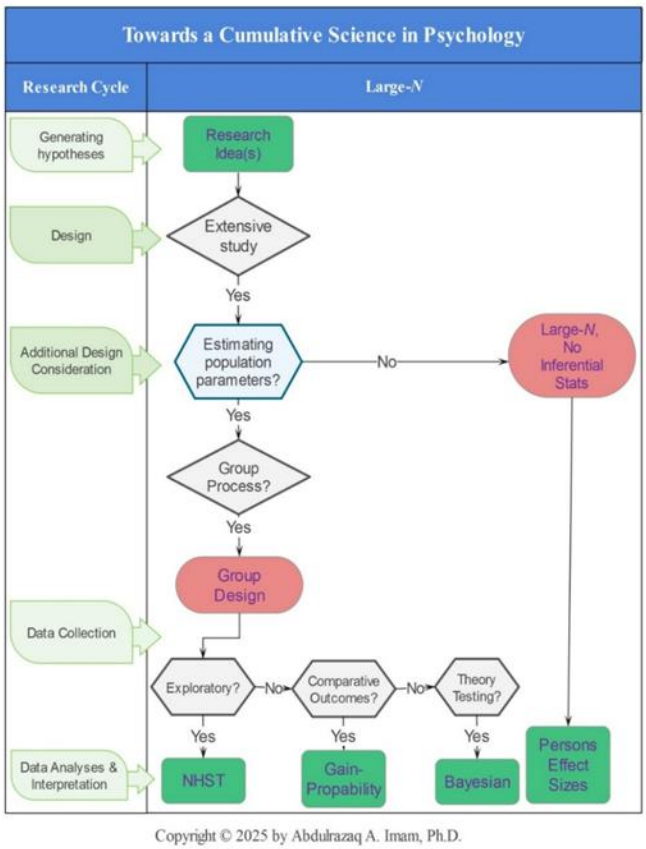

Figure 2. An updated new research cycle and decision algorithm for choosing research designs and statistical testing methods for extensive studies and group designs in psychological research (see text for details)

In the present paper, I illustrate how the new research cycle might guide research from start to finish. I present the case of academic help seeking (AHS) behavior based on a review reported by Li, Hassan, and Saharuddin (2023) in which they offer multiple areas of future research on the topic. I then provide methodological illustrations of how one could approach the suggested research areas from the standpoint of Imam (2024) recommendations calling for an overhaul of how psychologists conduct research toward achieving a cumulative psychological science devoid of wanton failures to replicate psychological research.

Methodological Illustration of the Process Approach

Li et al. (2023) provide a comprehensive review of the literature on academic help-seeking (AHS) behavior of college students. Their review included studies from nearly twenty countries, although most of them were from the United States of America. They identified five broad themes that describe students' help-seeking behaviors, including 1) definitions, theories, types and processes of the behavior; 2) the relationship of help-seeking and performance; 3) resource types, locations, and frequencies; 4) positive, negative, and irrelevant factors in help-seeking behavior; and 5) characteristics of online help-seeking behaviors.

The 55 target articles reportedly employed 5 categories of research, including quantitative, qualitative, mixed, quasi-experimental, and experimental designs (see Table 1). Table 1 shows that most of them (78%) were quantitative and only about 15% (8 articles) were qualitative. The table shows that there is a clear paucity of experimentation on this topic, with only one each of quasi-experimental and experimental designs.

Table 1. Research methods used in Li et al.'s (2023) target studies

Research Method	Number of Studies	Percent
Quantitative	43	78.18
Qualitative	8	14.54
Mixed	2	3.64
Quasi-Experimental	1	1.82
Experimental	1	1.82
Total	55	100

Research Questions

The four research areas they recommended were organized around categories involving 1) the nature of academic help-seeking behaviors including definitions, theories, and processes ; 2) the resources for academic help-seeking behavior varieties including mediated, in-person, online, etc.; 3) the factors that may be affecting academic help-seeking behaviors at individual or cultural levels, and mediators like peers, faculty, family, etc.; and 4) the methodologies to be deployed to study academic help-seeking behaviors to include longitudinal, experimental, qualitative research. The four categories provide an organizing framework for generating research questions (see Table 2). As we shall see, not all categories warrant actual research questions. For example, the

methodologies category's call for additional approaches is indirectly addressed by the eclectic nature of the process approach; various questions may be addressed by using different methodologies as dictated by the goals and interests of the researcher.

Table 2. Some potential research questions derived from the framework provided by Li et al.'s (2023) future research recommendations

Category	Research Question
Academic help-seeking behaviors	1. How do students define AHS behavior? 2. What types of assistance are offered to students by faculty and what is their impact of student AHS behavior?
Resources for academic help-seeking	1. How do students choose between formal and informal sources of assistance? 2. How do students choose between face-to-face and online sources of assistance?
Factors of academic help-seeking	1. What is the effect of individual characteristics like age, gender, experience on AHS behavior? 2. What is the effect of cultural and socio-economic background on AHS behavior? 3. What is the effect of academic self-efficacy, other people and environments, and different instructor characteristics on students' help-seeking behavior?

Admittedly, the tenor, content, and details of these questions would be different for different researchers based on their personal and/or professional goals, interests, and objectives, motivation, resource availability, and so on. The specific questions listed here, therefore, are purely for illustrational purposes. The objective is to use them as vehicles for exploring how the process approach would proceed compared to the standard approach commonly followed in extant, mainstream psychological research.

Design Questions

Based on the research questions listed in Table 2, what research design choices are indicated? In what follows, this question will be addressed for each of the potential research questions in Table 2. The process begins with design considerations not dictated by statistical issues. As noted above, a first determination is whether or not an extensive or intensive study is indicated. Only then do we move to statistical issues, or not, depending on our goals and dictates of the research question. Before we consider each question's design options, it is worthwhile to address some design issues relating to large-*N* and small-*N* designs.

Designs for Extensive Studies

There are two types of large-*N* designs that may fall under the extensive studies category, namely, between-subjects group designs in which different samples of participants received different treatments, typically requiring more participants, and within-subjects group designs in which all participants receive all treatments,

typically requiring a smaller number of participants. In general, the between-subjects group design is used to 1) compare different treatments, 2) avoid carryover effects, 3) study long-term effects, 4) reduce bias via random assignment, and 5) explore group differences. In contrast, the within-subject group design used to 1) reduce variability, 2) increase efficiency with small samples, 3) study changes over time, 4) compare conditions directly, and 5) minimize confounding variables. Incidentally, the lone experimental study (Santos et al., 2020) included in the Li et al. (2023) review used the latter design.

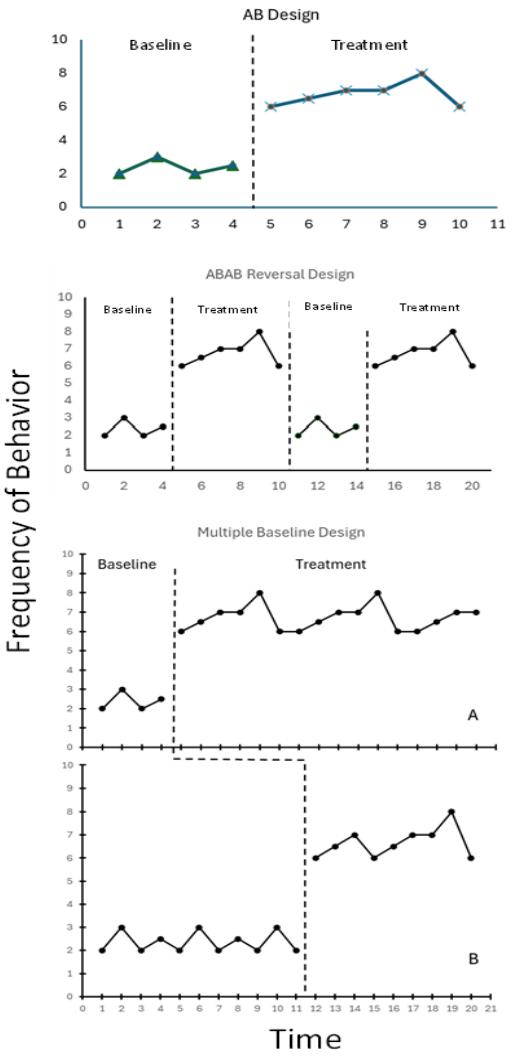

Figure 3. Hypothetical basic small-*N* designs from the simplest AB design to ABAB reversal design, and multiple baseline design. Each letter represents a phase of the experiment, A for baseline, B for treatment. As more treatments are added, more letters are added (e.g., ABCACD reversal with four treatments).

Small-N Designs

There are various small-*N* designs, including the simplest AB design, the ABAB reversal design, and multiple baseline design as shown in Figure 3. Each letter in the design name represents a phase of the experiment, A for baseline, B for treatment. Typically, as more treatments are added, more letters are added; for example, in an

ABCACD reversal design, there are three treatments, B, C, and D, in which the C condition and baseline are repeated. The AB design is the weakest design small-*N* design in that the effect of B may be due to a third variable; only a return to baseline can eliminate such possibility in an ABA design. In many applied situations, a return to baseline may not be desirable for practical or ethical reasons. In situations like that, a multiple baseline design provides an effective demonstration of reproducibility of effects across individuals and/or situations.

A note on transitions from phase to phase in small-*N* designs: there are rules for determining acceptable variability in data points and stability criterion that have to be met (Sidman, 1960; Poling et al., 1995).

Design Options for Each Research Question

Each research question is now queried as to what design options are indicated.

How do students define AHS behavior? Because the question seeks to determine students' perspective on help-seeking behavior, the goal would be to seek their opinions via a survey of their thinking. As such, an extensive study of many students is indicated. An intensive study is in fact counterproductive and would be uninformative. The requirements of conducting survey research will therefore be in play. The question does not call for an experiment.

What types of assistance are offered to students by faculty and what is their impact of student AHS behavior? Like the first question above, this one also requires that we determine what faculty help is available to students. The goal then would be to survey various faculty on how, where, and when they offer assistance to students in their various courses, in and out of the classroom, and on their perceptions of the impact they have on their students. Again, an extensive survey of faculty is therefore indicated, not an experiment.

How do students choose between formal and informal sources of assistance? This is not a survey question. It can be an extensive study if there is interest in population parameter estimation. In that case, both between-subjects and within-subjects group designs are possible, depending on the further consideration that we want to explore group differences vs. compare conditions directly and minimize confounding variables.

A between-subjects group design could work with three groups of participants in a control group without any help-seeking intervention, an experimental group receiving formal help-seeking intervention, and another receiving informal help-seeking intervention (see Figure 4, top). A within-subjects group design would expose each participant to all conditions including no exposure, exposure to formal and to informal help-seeking interventions (see Figure 4, bottom).

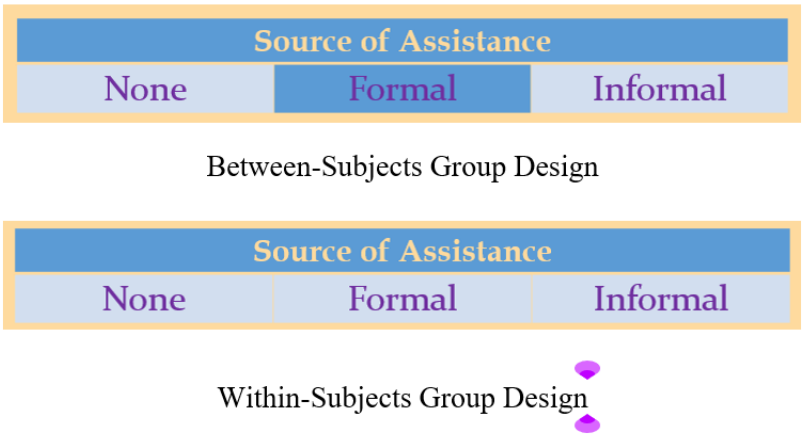

Figure 4. Between-subjects group design (top) and within-subject group des..gn (bottom) for comparison of formal and informal help seeking behavior

If interest is in individual choice processes under different sources of assistance, this question also can be an intensive study, in which case, a small-*N* design that compares choices under no intervention (baseline) with an intervention involving both formal and informal interventions. The multiple baseline design is the choice design here because of the nature of the behavior (see Figure 5). Once a student has developed help-seeking behavior, one would not want them to stop by reversing the condition to baseline as would be required in a reversal design.

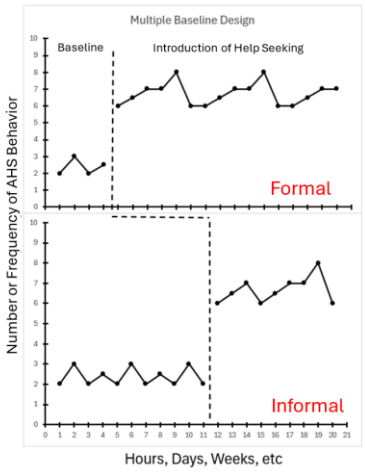

Figure 5. Hypothetical multiple baseline design for formal and informal AHS behaviors of one student.

The delayed introduction of the second treatment allows the acquired behavior to continue while still assessing the new intervention. The multiple baseline here provides comparisons across formal and informal settings, but also can be implemented to compare across courses, for example. Figure 5 depicts the procedure for one student. Another student may experience the sequence during intervention by receiving the informal condition first to counterbalance.

A more complex multiple baseline also could be implemented in which two students are both exposed to formal

and informal help-seeking in a staggered version with a delay in exposing Student B to the two types of assistance (see Figure 6).

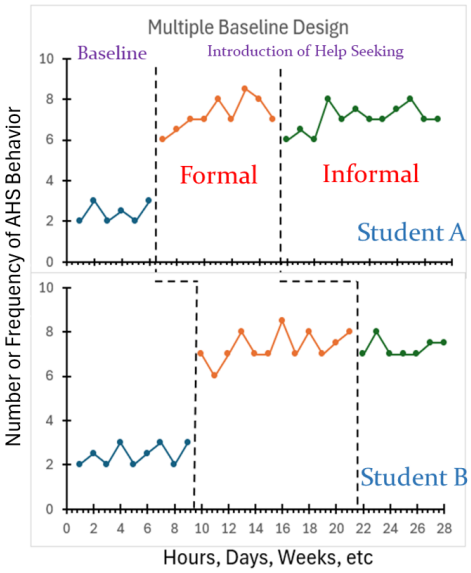

Figure 6. A more complex hypothetical multiple baseline design for formal and informal AHS behaviors of two students, A and B, both exposed to formal and informal help-seeking in a staggered version with a delay in exposing Student B to the two types of assistance.

How do students choose between in-person and online sources of assistance? This question is very similar to the last one in comparing in-person with online sources of assistance. With interest in estimating population parameters, the study can be extensive with both between- and within-subjects group designs. In this case, a between-subjects group design with three groups of participants in a control group without any help-seeking intervention, an experimental group receiving in-person help-seeking intervention, and another receiving online help-seeking intervention (see Figure 7, top). A within-subjects group design would expose each participant to all conditions including no exposure, exposure to in-person and to online help-seeking interventions (see Figure 7, bottom).

Type of Assistance		
None	In Person	Online

Between-Subjects Group Design

Type of Assistance		
None	In Person	Online

Within-Subjects Group Design

Figure 7. Between-subjects group design (top) and within-subject group design (bottom) for comparison of in-person and online help seeking behavior

Again, like in the previous question, with interest in individual processes in seeking help in person or online, an intensive study is indicated using multiple baseline designs that compare across in-person and online settings for help-seeking behavior of one student (see Figure 8).

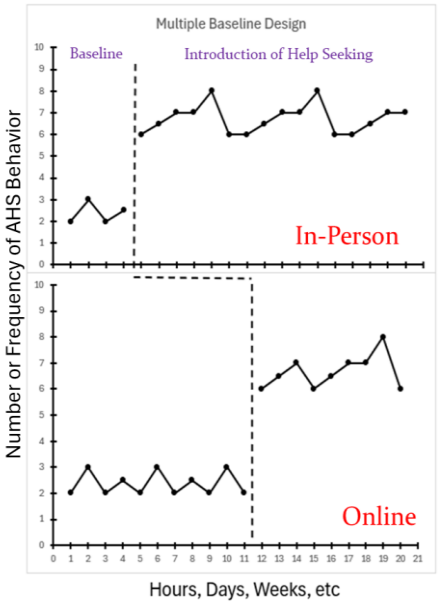

Figure 8. Multiple baseline design for in-person and online AHS behaviors of one student.

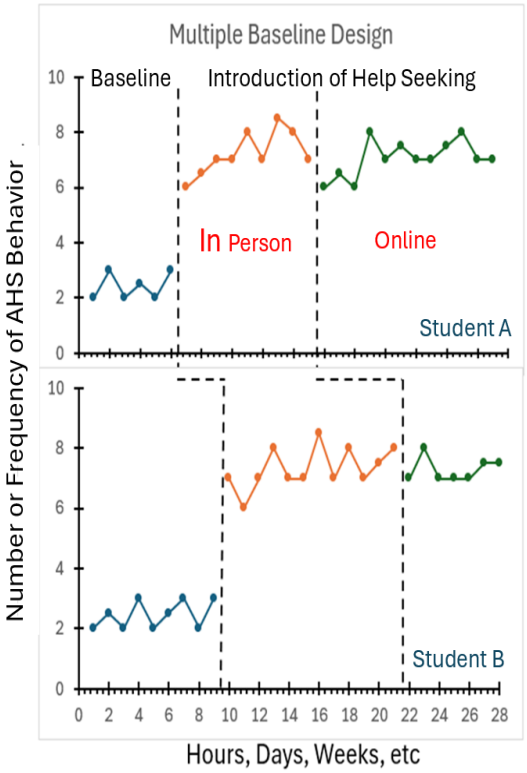

Figure 9. A more complex multiple baseline design for in-person and online AHS behaviors of two students, A and B, both exposed to formal and informal help-seeking in a staggered version with a delay in exposing Student B to the two types of assistance.

A more complex multiple baseline would involve two students exposed to in person and online help-seeking intervention staggered with a delay in exposing Student B to the two settings (see Figure 9). The multiple baseline also can be implemented to compare across courses.

What is the effect of individual characteristics like age, sex, experience on AHS behavior? Age, sex, and experience are readily subject to experimentation. Depending on interest in estimating population parameters, the question can be addressed with an extensive study. adopting a between-subject group design for sex and years of experience in college (see Figure 10). This represents a 2x4 factorial design in which eight different groups of participants consisting of male and female students in first through fourth year of college would be recruited. Similarly, a 3x4 factorial design for age and years of experience in college could be implemented (see Figure 11) in which students aged 18, 24, and 30 with first through fourth year of college experience would serve.

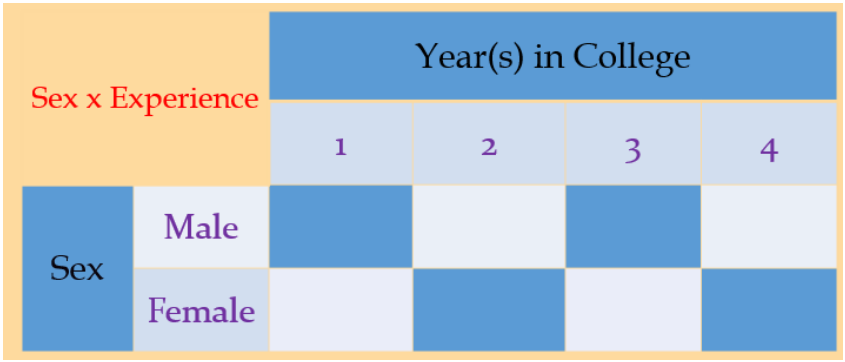

Figure 10. A 2x4 Between-subject group design for sex and years of experience in college

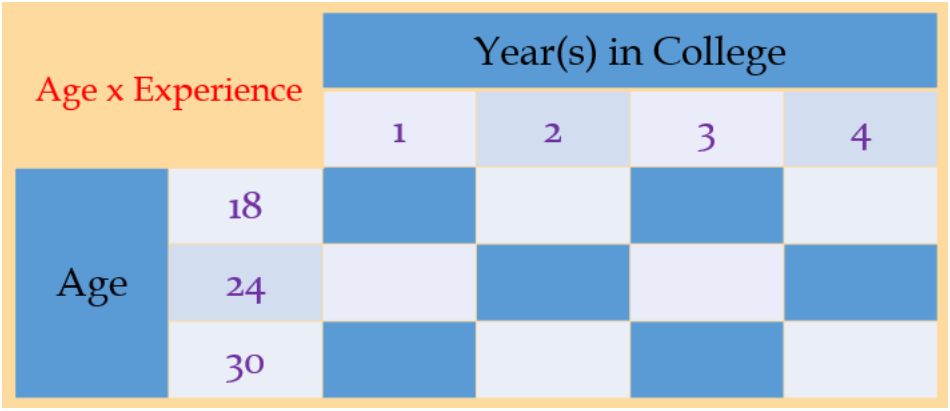

Figure 11. A 3x4 Between-subject group design for age and years of experience in college

Within-subjects group designs would not be feasible for this question because it targets group variables that cannot be explored within participants. Neigther would repeated measures small-*N* designs.

What is the effect of cultural and socio-economic background on AHS behavior? With interest in estimating population parameters, the question can be addressed with an extensive study that adopts a between-subject group design for socio-economic (low, medium, and high) background and help-seeking setting (formal

and informal) in a 3x3 factorial design including a control group without help-seeking facility (see Figure 12). A similar 3x3 factorial design for help type (in person, online, and none) and cultural background (African, Asian, and European) could be implemented (see Figure 13). As veritable group variables, neither socio-economic nor cultural background could be manipulated within participants; therefore, no within-subjects group design nor small-*N* design is feasible for this question.

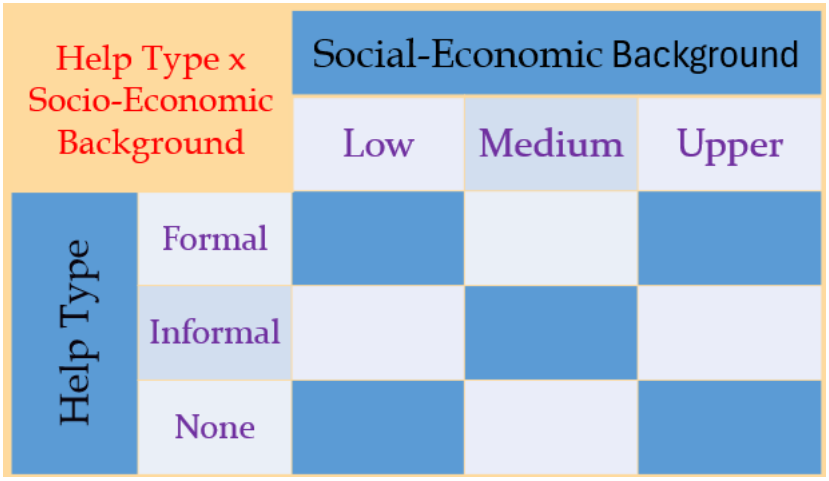

Figure 12. A 3x3 Between-subject group design for type of help and social-economic background

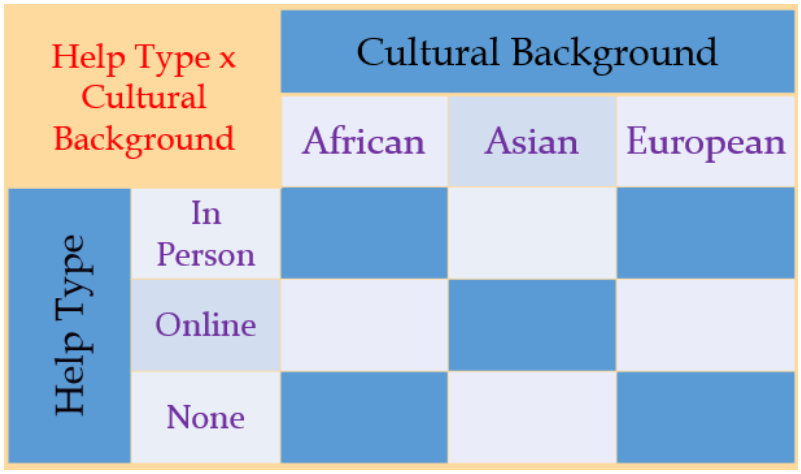

Figure 13. A 3x3 Between-subject group design for type of help and cultural background

What is the effect of academic self-efficacy, other people and environments, and different instructor characteristics on students' help-seeking behavior? An extensive study is indicated, and with interest in population parameter estimation, a 2x4 factorial design for academic self-efficacy (high, low) and people helpers (peers, family, instructor, and teaching assistant; see Figure 14) that combines the people and instructor characteristics in the question provides a viable design option for the question. Similarly, a 2x3 factorial design for academic self-efficacy (high and low) and environment (home, school, and online) could be implemented (see Figure 15). As with the previous two questions, within-subject group designs and small-*N* designs are not feasible due to the nature of the variables involved, particularly academic self-efficacy.

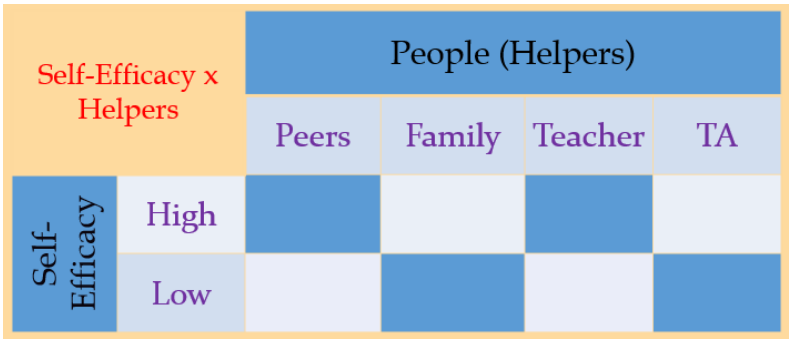

Figure 14. A 2x4 Between-subject group design for self-efficacy and people

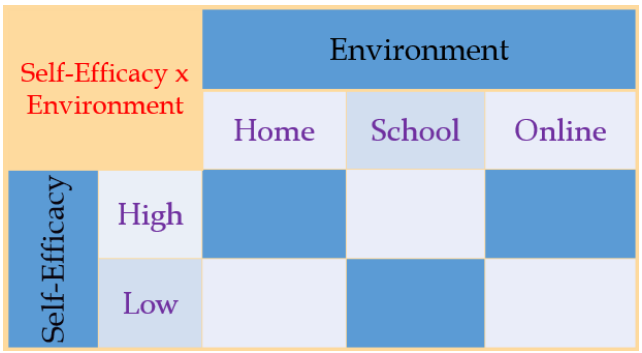

Figure 15. A 2x3 Between-subject group design for self-efficacy and environment

Data Handling

Unlike in standard research practice, data handling in the process methods approach represented in this paper is influenced by the research question, not just statistical considerations. The influence may be direct, such as in the first and second research questions above in which the survey nature of the research dictates the type of data to be collected and analyzed. The influence may be indirect as was the case in the remaining research questions in which the experimental design option dictated by the research question would inform the type of data to be collected and analyzed.

Imam (2024) had suggested two options for data analysis depending on whether a study is deemed exploratory or designed for theory testing. The argument was that given its limitations, only exploratory studies may appropriately deploy NHST analysis, and that Bayesian analyses are better suited for comparing theoretical models. In the present study, the range of analytic tools available for various purposes is updated for further clarity and completeness, recognizing the need to embrace various interests of professional interest in psychological research. Specifically, as Figure 2 shows, an additional data analytic question that addresses whether one wishes to compare outcomes between members of different groups is introduced.

Trafimow and colleagues have developed alternatives to NHST and effect size approaches that address two of their shortcomings, namely, the role of sample size and the meaning of a significant finding. The first they tackle by providing researchers the means to ask how close they wish to be to the population parameter, and its

probability, predata collection (Trafimow et al., 2018), using the a priori procedure (APP; see Trafimow et al., 2024). The second enables researchers to ask the often-useful question, what is the probability that a random member of one group (e.g., experimental) would be more (or less) likely than a random member of another group (e.g., control) to behave in a certain way and to what extent? (e.g., Trafimow et al., 2022; Trafimow et al., 2024). This they accomplish through the gain-probability (G-P) diagram, which, in its various forms, allows the researcher to answer such comparative outcome questions, a feat NHST and effect size calculations are unable to perform (Trafimow et al., 2024).

When the goal does not involve population parameter estimation, a group design is not indicated, but a Large-*N* study without inferential statistics is. Imam (2024) provided no explicit analytic tool for handling such scenario, except to note that Guilford and Dallenbach, (1925) and Oberly (1928) deployed their larger *N* experiments for confirmational purposes but without reliance on statistical inference for interpretation of their findings, suggesting the possibility of using such measures as persons as effect sizes (Grice et al., 2020). The person effect size is devised to address the question: "How many people in the study behaved or responded in a manner consistent with theoretical expectation?," indexed by "*percent correct classifications* (*PCC*)" (Grice et al., 2020, p. 444). Figure 2 has updated the large-*N* portion of the decision tree for the process method to acknowledge it. Such measures would be appropriate for any of the research questions above qualified for an extensive study, but without a goal to estimate population parameters.

Table 3. Statistical predata and postdata collection requirements for each approach to data analysis and interpretation

	Requirements	
Statistical Approach	Predata	Postdata
NHST	Specify alpha and/or *p*-value Specify relevant population Determine normality Conduct power analysis Randomly sample participants	
G-P Analysis	Complete a priori procedure (APP) to determine sample size	Conduct G-P analyses and draw G-P diagrams for interpretation
Bayesian analysis	Determine priors and/or prior odds	Determine posterior odds
Person ES	None	None

Data handling in the designs suggested above for the research questions curled from Li et al.'s recommendations for future research require specific procedures dictated by the type of statistical analysis adopted. Each of the statistical approaches had its own predata collection and postdata collection procedures that the process method would make no exceptions for in the interest of achieving a cumulative science. The adverse consequences of wanton violations of assumptions, requirements, and processes experienced with NHST provide ample reasons to avoid the same fate going forward. Table 3 presents the minimal requirements for each statistical approach

discussed in the present study, except persons as effect sizes (Grice et al., 2020), which has no pre- or postdata collection requirements.

NHST Data Handling

Table 3 shows that predata collection requirements in NHST analysis include the specification of alpha (Cohen, 1992) and the *p*-value, as well as the relevant population of interest for the purpose of estimating parameters. Various test statistics in NHST require normality in the distribution of scores (Shavelson, 1988). Power analysis is required to determine sample size, *N* (Cohen, 1992). Finally, random samples from the relevant population (Poling, Methot, & LeSage, 1995) is essential to endure representativeness and generalizability of the results.

The postdata collection requirement is the determination of *p*-value following computations of requisite test statistic (Shavelson, 1988). Needless to say, the mean and standard deviation are essential descriptive metrics of particular interest in NHST analysis.

G-P Analysis Data Handling

Gain-probability analysis involves determination of sample size using the a priori procedure (APP) prior to data collection (see Table 3). Trafimow et al. (2024) provide links to online apps for the calculations required to complete the APP. The unique attributes of the sample size determination which approximates population parameters desired by the researcher places the APP in better stead than the power analysis of NHST and effect size procedures (see Trafimow et al., 2018, 2022, 2024). While adaptable for normal distributions with mean and standard deviations, APP analysis has the added benefit of handling skewed normal distributions with location (equivalent to the mean), scale (standard deviation), and shape parameters. Trafimow et al. (2024) provide various program links for different skewed normal conditions that aid in determination of the sample size.

Having determined the sample size that ensures close approximation of population parameters, the G-P analysis and diagrams enable interpretation of outcomes by helping the researcher and other stakeholders "to estimate the probabilities of being better off or worse off, in one condition or the other, by varying degrees" (Trafimow et al., 2024, p. 12).

Bayesian Analysis Data Handling

It is widely acknowledged that Bayesian analysis, in comparison to NHTS, is most suitable for model comparison in addition to its hypothesis testing and parameter estimation functions (e.g., Campbell & Gustafson, 2023; Colling & Szucs, 2021; Kelter, 2020; Kruschke & Liddell, 2018a, 2018b). Predata collection requirements include determining priors and/or prior odds used in combination with the postdata collection posterior odds to calculate the Bayes Factor (BF) used for interpretation. Pfadt et al. (2022) and Wagenmakers,

E.-J., Love, J., Marsman, M., Jamil, T., et al. (2018b) describe the JASP software that aid in such analyses.

None of the research questions emanating from Li et al.'s recommendations for future research appear to have theoretical underpinnings; only three of the 55 studies included in the review by Li et al. (2023) have some bearing on theory or theoretical considerations. Consequently, adoption of a Bayesian approach to data analysis and/or interpretation is not indicated, based on the theory testing role assigned Bayesian analysis in Imam's (2024) decision tree (see Figure 2).

Although only three of the target articles relate to theory as indicated, the AHS behavior literature does provide areas of opportunities for theory testing, including various models of self-regulated learning closely associated with Albert Bandura's social learning theory (Fong et al., 2023; Sun et al., 2018; see also Green & Azeveda, 2007) and self-presentation theory (Long & Neff, 2018). Both of these and other theories can be tested using either the G-P analysis or Bayesian analysis, both of which are amenable to theory testing, unlike NHST.

Conclusions

From the foregoing illustrations, it is clear that when research questions drive the research process and design selection instead of just statistical considerations, either Large-*N*, small-*N*, or both designs may be deployed, and when estimating population parameter is the goal of an extensive study, experimentation may involve between-subjects or within-subjects Large-*N* designs. The use of inferential statistics adopted for the group designs depend on the research design indicated by the research question. The literature on academic help-seeking behavior already displays a dearth of experimentation as reported by Li et al. (2023) with only one out of 55 studies used in their review. The process approach adopted here provides ample avenues for future experimental work on AHS behavior that appears presently lacking. The exercise shows that it is really all about the right tools for the right questions; there is no one size fits all. What we need is to reorient for developing appropriate expertise for judicious judgement on conducting sound psychological research. The cumulative science will evolve.

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Investigation of Digital Literacy Levels of Pre-service Social Studies Teachers

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Abstract: Today, the rapid development of digitalization has made it compulsory for individuals to have digital literacy skills. Digital literacy used in the field of education has become a necessity for teachers and prospective teachers, and especially the competencies of prospective social studies teachers in this field have become an important subject of investigation. Social studies course is a course that aims to gain skills such as critical thinking and media literacy. These skills can be supported by using digital technologies effectively so that a more efficient course environment can be created through digital applications. This study is a qualitative research that aims to examine the digital literacy levels of pre-service social studies teachers and a case study design was used. The data obtained were evaluated by content analysis method. In the light of the data obtained; three main principles stand out in the internationally accepted definitions of digital literacy. These are; having the ability to access and effectively use software and hardware applications, the ability to understand digital media content and applications with a critical perspective, and the process of producing knowledge and capacity through digital technology. It is thought that this study will contribute to the design of training programs to improve the digital literacy skills of pre-service social studies teachers.

Keywords: Digital Literacy, Digitalization in Education, Pre-Service Teachers

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Introduction

Technology has entered almost every moment of our lives and has become a tool that makes our lives easier (Sürer, 2020). People have to use one or more technological tools to communicate in many areas of their lives. These tools include telephone, internet and computer (Akman, 2024). Developments in technology are increasing day by day and this situation is reflected in education life (Çakır et al., 2019; Coskun, 2025; Gulnar, 2025; Kibici, 2022a, 2022b, 2025; Kilincer, 2021; Ozdemir, 2022; Ozkan, 2022; Ozturk & Ozturk, 2022, 2024; Tekin, 2025). Advances in digital technology, together with the existence of the Internet, have had a significant impact on the world of education. The Internet is driving the learning revolution and requires all educational

constituents to adapt and equip themselves with various skills in information seeking (Rizal, Rusdiana, Setiawan, Siahaan, & Ridwan, 2021). 21st century is a period in which technological developments accelerate (Sürer, 2020). In the 21st century, which is also called the information age, people need to have some basic skills in order not only to store information, but also to select, analyse, evaluate it and use the information obtained in their daily lives and turn it into a product (Erol, 2021). Another development that comes with digitalisation is the elimination of the concept of time. Now people can access the information they want easily and comfortably. Accordingly, the importance of distance education applications has increased (Ataş & Gündüz, 2019).

Lessons held in digital environments by moving away from traditional methods will both make the lesson more interesting and make the teacher-student relationship more interactive (Karakuş & Ocak, 2019). Students' use of various digital media will provide a positive incentive to develop knowledge, develop skills, and prepare for a good career in the future (Rizal, Rusdiana, Setiawan, Siahaan, & Ridwan, 2021). What is important here is that individuals act according to moral principles and use technology in a controlled manner where necessary (Karakuş & Ocak, 2019). As digital technologies become an integral part of people's lives, access to digital literacy is of great importance in different areas such as workplace, finance, education, health, transport, leisure and communication (Nurhayati, 2024). Advances in technology have developed the world, and as the world has developed, human needs have changed. This has been effective in increasing literacy skills. One of these skills is literacy skill (Duran & Özen, 2018). Digital literacy is extremely important because digital technology is an integral part of modern society, fostering economic development and helping to face the challenges and perspectives of modern digital society (Tabieh, Hamzeh, Abu-Foudeh, Jarrar, Al-Manaseer, Al-Shawabkeh, & Seikaly, 2021). Digital literacy enables individuals to be dynamic in their present and future lives and to use different technological tools in the right place against the problems they face. In addition, digital literacy is the ability to access, manage, understand, integrate, integrate, communicate, evaluate and create information safely and appropriately through digital technologies for employment, good jobs and entrepreneurship (Anisimova, 2020). Digital literacy can be used as a tool in accessing the right information by using technological tools and in solving problems experienced in technology (Bircan & Aydın, 2024). Since the 1980s there has been a major effort to provide technology in schools because educational informatics has long been thought to prepare students with the necessary digital skills for their future careers (Nguyen & Habók, 2024). The FATİH (Movement for Increasing Opportunities and Improving Technology) project, which was carried out in our country for the advancement of digital literacy, is one of the steps taken to bring education and technology together and to create an interactive classroom environment (Bircan & Aydın, 2024). Digital literacy skills are among the specific aims of the social studies course. In this direction, it is aimed to use technology effectively and correctly (Yaman, 2019). Having digital competences is of great importance for both students and teachers in terms of collaborative learning, providing permanent learning, making lessons more meaningful and fun (Korucu, 2020). Teachers should have a set of competences to become professional teachers by using technology for communication, personal development and educational development activities. also through the use of digital technology, teachers can give new meaning to learning activities (Rizal, Rusdiana, Setiawan, Siahaan, & Ridwan, 2021). Teachers who do not have this skill have problems in using technology and

transferring technology to the classroom environment. This situation made it necessary to examine the digital literacy levels of teachers (Sulak, 2019).

Purpose of the Research

In the research, it is aimed to examine the digital literacy skills of 2nd, 3rd, 4th grade social studies teacher candidates studying at Süleyman Demirel University Faculty of Education. In the research, answers to the following questions are sought.

1. How do pre-service social studies teachers define digital literacy?
2. To what extent do pre-service social studies teachers consider themselves competent in terms of digital literacy?
3. What difficulties do pre-service social studies teachers encounter when using digital technologies?
4. What can be done to improve their digital literacy skills?
5. What do pre-service social studies teachers think about the impact of digital technologies on education in the future?

Method

Qualitative research method was used in this study, which aimed to examine the digital literacy of pre-service social studies teachers. Qualitative research enables in-depth examination and explanation of the attitudes, behaviours, actions and general experiences that characterise the human condition. When used in education, it provides a basis not only for understanding phenomena, but also for challenging and even improving situations that affect relevant educational actors (Pérez, 2024). Case study design was used as the research design. According to Dawidowicz (2011), case study is a flexible design that can be used for everything from examining the factors affecting the behaviour of individuals to understanding the needs of people in certain situations from their point of view.

Working group

This study was conducted with 2nd, 3rd and 4th grade students studying at Süleyman Demirel University Faculty of Education. The research was carried out with 13 participants, 7 of whom were female and 6 of whom were male.

Data Collection and Analyses

Semi-structured interview method, which is one of the qualitative data collection methods, was used in the study. In this method, the interviewer asks questions prepared within the framework of a predetermined subject or field, but has the flexibility to ask additional questions to obtain more detailed information about these questions (Yıldırım, & Şimşek, 2021). In order to collect the research data, firstly the literature was analysed

and then interview questions consisting of semi-structured questions were prepared. The 5 interview questions prepared in the form of open-ended questions were examined by taking the opinions of the relevant academicians and their suitability was examined and arrangements were made. In this study, a pilot study was conducted to evaluate the validity and applicability of the data collection tool. The pilot study was conducted with 2 pre-service social studies teachers. During this application period, all interviews were audio recorded with the approval of the participants. Interviews were conducted individually with the participants and the interviews lasted an average of 20 minutes. Participants were informed about the purpose of the study and it was stated that personal information would be kept confidential. After the semi-structured interview form was applied, the data obtained from the pre-service teachers were tabulated and similar expressions were gathered under a single sentence. In the study, the abbreviations in the quotations made from the participant statements were made as follows: Female participants were coded from P1 to P7 (1st-7th participants) according to the participant order. Male participants were coded from E1 to E6 (participants 8-13). The questions in the interview form were asked to the participants in a complete manner, and supplementary follow-up questions were asked when necessary to elaborate the answers given and to develop a deeper understanding. In this context, the main questions in the interview form are as follows;

1. What do you think digital literacy is?
2. Do you consider yourself sufficient in digital literacy? Why?
3. What are the difficulties you face when using digital technologies?
4. Do you think that digital literacy is sufficiently covered in your university education?
5. How do you think digital technologies will shape education in the future?

5.1. What are the positive and negative aspects?

5.2. Which characteristics should teachers have?

Results

The findings obtained from the research were organised around 5 main themes: “Defining Digital Literacy”, “Self-efficacy Perception”, “Challenges Encountered”, “Development Methods”, “Future Effects of Digital Technologies on Education”.

Defining Digital Literacy

In this study, the participants' views on the definition of digital literacy were analysed and the codings based on the findings are presented in Table 1.

Table 1.

Code	Frequencies	Percentage %
Access to information and accuracy assessment	5	%38.46
Effective use of digital tools	4	%30.77

Analysing social media and news	4	%30.77
Adaptation to technological developments	3	%23.08
Digital skills in academic research	3	%23.08

According to the findings obtained in the study, the majority of the participants defined digital literacy as access to information and accuracy assessment. One of the participants, E5, said: 'It is a skill gained to use today's technology well. And I think it is very necessary especially in the 21st century. Whether on the internet or elsewhere, there is a lot of fake news, information pollution. The more digitally literate we are, the more we avoid them, the more we are not fooled. This pushes us to research to find the right information.' statements support the findings. It was observed that the participants also defined digital literacy with the effective use of digital tools, social media and analysing news. Some of the views of the participants that support each other are as follows;

> *'I can say that human beings keep up with the developing technology. For example, if we can use the smart board at school, I think we are digital literate.' (P6)*

> *'Digital literacy is the ability to follow the social agenda, interpret it or make an inference. I think it is digital literacy to believe any event or issue on the agenda by actually researching it instead of believing it directly.' (E2)*

Self-efficacy Perception

The views of the participants regarding their self-efficacy perceptions on digital literacy were analysed and the coding of the findings obtained in this context are presented in Table 2.

Table 2.

Code	Frequencies	Percentage %
Self-perception of inadequacy	7	%53.84
Technological knowledge and skills development	6	%46.15
Investigating the accuracy of information	5	%38.46
Personal development with digital tools	4	%30.76
Adaptation to digital over time	3	%23.07

According to the results obtained, the most frequently emphasised theme is that the participants do not consider themselves sufficient in digital literacy. One of the participants, P2, said: 'Like many people living in this world, I do not consider myself sufficient in this regard, because technology is constantly developing and never stands

still. For example, I should be more careful in researching and collecting information. Although I know that not every source is reliable, I can sometimes be inadequate in comparison.' supports the findings. In addition, technological knowledge and skill development are the most frequently expressed views of the participants. Some of the opinions supporting the findings of the participants are as follows;

> *"I try to improve myself. I take trainings on technology. For example, I am currently learning how to use a fast keyboard on the computer." (E6)*

> *"In the institution where I work, the trainings are given practically, if they were not given practically, I would not understand and I would not be able to improve myself."(P6)*

A common view among the participants that it plays an important role in developing digital literacy skills was investigating the accuracy of information. The participants emphasised that it is important to question the reliability of information on the internet and to conduct comparative research. Some of the statements of the participants regarding these views are as follows;

> *"I think there is a lot of information pollution, we need to investigate the accuracy of the information ourselves. We need to research not from a single source but from many sources."(P4)*

> *"For example, if I see a news item on a different news site, I think that news item is true. In order to improve this, I think I should evaluate my prejudices independently of my own opinion." (E3)*

Challenges Faced

In the findings obtained, the difficulties encountered by the participants while using digital technologies were examined and the findings obtained are presented in Table 3.

Table 3.

Code	Frequencies	Percentage %
Technology utilisation challenges	8	%61.53
Information pollution	5	%38.46
Problems of access to technology (internet, etc.)	5	%38.46
Methods of access to accurate information	5	%38.46
Lack of technical skills	4	%30.76
Search for environmental support	3	%23.07
Paid applications and resources	2	%15.38

According to the findings obtained in the study, the majority of the participants mentioned the difficulties of using technology while using digital technologies. They also emphasised the difficulties they experienced at the beginner level in the process of using technology. In particular, it was stated that the process of learning certain features of computers, phones and other digital devices was a time-consuming and challenging experience. Participant P1's statement "For example, when I first used the computer, I had difficulties and I did not know some aspects of it. Like Excel, you do not know anything at first, but after you learn it, it becomes easier'. In addition to these views, the other most frequently expressed views were information pollution, problems of access to technology, and methods of accessing accurate information. Some of the opinions of the participants regarding these views are as follows;

> *"I have the most difficulty in accessing the right information. I think that not only the internet but also books should be used. In addition to looking at the website, many sources should be looked at." (P4)*
>
> *"I think that the most deficient part of today's world is book searching because I think it is very wrong to access information over the internet. I think that we should go back a little more. I think that research should be done by looking at many sources, not just one source."(P7)*
>
> *"I think the main problem is at the internet stage, I think we have problems with digital internet. Infrastructures can be developed for this."(E1)*
>
> *"I could not find Turkish resources because I could not find many resources related to the sectors I was dealing with, so it was very tiring for me. I look at foreign sources for this."(E6)*

Development Methods

In the findings obtained in the research, the methods used by the participants to develop their digital literacy skills were examined and the coding of the findings obtained are presented in Table 4.

Table 4.

Code	Frequencies	Percentage %
Digital Literacy Education and Competence	12	%92.30
Practical and Applied Training	9	%69.23
Recommendations and Training Development	7	%53.84
Media Literacy and Critical Thinking	6	%46.15
Use of Digital Tools and Accessibility	5	%38.46
Technological Inadequacies and Infrastructure Problems	4	%30.76

According to the findings obtained, digital literacy education and competence were mentioned the most in the development of digital literacy skills of the participants. The majority of the participants stated that digital literacy education was insufficient. They emphasised that more practical lessons and applied studies with digital tools should be done in the education, and that this education should not only be theoretical but also practical. Some of the participants' views on the subject are as follows;

> *"I do not think that the education we received at the university was sufficient because we have just encountered it as a fourth year student." (P2)*

> *"I don't think it is given enough space. I don't think that something explained on the blackboard is a real education."(E1)*

> *"I don't think about it because I feel as if we don't do anything about digitalisation. There is a computer course, but it is only theoretical, not practical." (E5)*

Along with these views, some participants mentioned practical and applied training in their views on the development of digital literacy skills. They stated that digital literacy education is only based on a theoretical basis, but there is a lack of practical training. I don't think that something explained on the blackboard is a real education. "If it was a practical education, we could understand and comprehend what the teacher explained better. As a person does something, he/she can gain his/her skills. For example, children gain speaking skills as they talk." supports the findings.

Future Impacts of Digital Technologies on Education

In the findings obtained, the views of the participants on the future effects of digital technologies are presented in Table 5.

Table 5.

Code	Frequencies	Percentage %
The need to improve teachers' digital literacy skills	8	%61.53
Development of critical thinking skills	7	%53.84
Fast and easy access to information	7	%53.84
Increasing applied training	6	%46.15
Teachers being open to innovations	6	%46.15
Integration of technology into pedagogical methods	6	%46.15
Solving technological infrastructure deficiencies	5	%38.46

Increasing in-service trainings	5	%38.46
Integration of technology into the learning process	5	%38.46
Widespread use of digital classroom environments	4	%30.76
Balancing online and face-to-face training	4	%30.76
Exposure of students to distractions	3	%23.07
Increase in technological applications such as virtual museums	3	%23.07
Reduced social impact in education	2	%15.38

According to the findings obtained, the majority of the participants emphasised the need to develop the digital literacy skills that teachers should have while talking about the effects of digital technologies on future education and mentioned the importance of these skills on education and their effects on students. 'Current teachers are not very innovative; this makes it difficult for them to guide students in the digital world.' His statement supports the findings. In addition, the development of critical literacy skills is also among the views of the majority of the participants. One of the participants, E2, said, 'With the media literacy course, I realised the importance of critical thinking. I especially look more carefully at technological content and news. Digital literacy training can be a tool to develop critical thinking.' His statement supports the findings. . In addition, increasing practical training, teachers being open to innovations, integration of technology into pedagogical methods are among the majority views. Some of the opinions supporting the findings of the participants are as follows;

> *"Theoretical knowledge is given but nothing is taught in practice. If more practical information was given at the faculty, a better learning environment would be created."(E2)*

> *"Teachers need to be innovative. We must be open to continuous developments; otherwise we will fall behind the age."(E4)*

> *"If the infrastructure had been provided in digital education projects such as the Fatih Project, technology could have been integrated more effectively into pedagogical methods." (E1)*

In addition to these views, the necessity of balancing online and face-to-face education with the spread of digital classroom environments is among the views expressed by the participants.

Discussion and Conclusion

Today, digital technologies have become an important tool in the field of education. These tools are of great importance in terms of transferring information correctly and using it in the right place. In the 21st century education model, the digital literacy skills of pre-service teachers directly affect their professional development and future teaching processes.

In this study, the digital literacy levels of pre-service social studies teachers were analysed qualitatively and the findings were grouped around five main themes. According to the results of the research, participants generally define digital literacy in terms of access to information, evaluation of information and effective use of digital tools. This shows that they have developed an awareness of questioning the accuracy of information and critical thinking beyond accessing digital information. Three main principles stand out in internationally accepted definitions of digital literacy. These are; having the ability to access and effectively use software and hardware applications, the ability to understand digital media content and applications with a critical perspective, and the process of producing knowledge and capacity through digital technology (Taskiran, & Salur 2021). Based on these statements, the answers given by the participants about the definition of digital literacy are in line with these principles.

Most of the participants associated digital literacy with the skills of accessing accurate information and using technology effectively. However, it was determined that they had difficulty in using digital tools effectively. The most common difficulties encountered in the use of technology include lack of technical knowledge and access problems. Çelikkaya, & Köşker (2023) concluded that the technical and cognitive competences of social studies teachers are weak. This coincides with the findings of this research.

In the study conducted by Bahar, Uludağ and Kaplan (2009), significant differences were found in the attitudes of teachers with internet connection towards computers, but no significant difference was found in their attitudes towards the internet. In addition, it was stated that the frequency of internet use was effective on the level of digital literacy and as the frequency of use increased, the digital competence scores of individuals increased. It is seen that it is similar to the findings of this study. Pre-service teachers who use the Internet more frequently consider themselves more competent in terms of digital literacy. A significant portion of the participants do not find themselves sufficient in digital literacy. This situation is associated with a lack of technological knowledge, inadequate practice and difficulty in adapting to rapid changes in the digital world. Moreover, lack of technical skills, information pollution and infrastructure problems are the main challenges in the use of digital technologies. As a result of the research, it was determined that the participants predicted that the digitalisation process of education will accelerate in the future. In this process, participants emphasised that teachers should be open to digital technologies, develop critical thinking skills and have digital pedagogical competences. According to Haryanto et al. (2022), digital literacy plays a decisive role in students' critical thinking skills. Teachers‘ application of discussion-based teaching methods that support students’ active participation in the classroom environment, as well as monitoring and evaluating learning processes will contribute to the development of students' critical thinking skills. In this context, digital literacy skills are considered as one of the building blocks of an effective and efficient learning process.

In the study, in-depth opinions of the participants were analysed with qualitative methods. However, when the related literatures are examined, studies conducted with quantitative method are in majority and digital literacy levels are measured with tests. The differences in the methods used were effective in the diversification of the findings. In the study conducted by Yontar (2019), the digital literacy level of pre-service social studies teachers

was expressed as medium, while this level was expressed as high in the studies conducted by (Gülmez, 2024; Köşker & Çelikkaya, 2023; Özçelik & Yılmaz, 2024). As can be seen, it is possible to encounter different findings in the literature.

In a study conducted by Özerbaş and Kuralbayeva (2018) on the digital literacy levels of pre-service teachers in Turkey and Kazakhstan, contrasting results were found. According to the research, pre-service teachers in Turkey feel themselves more competent in digital literacy. The analyses conducted on the basis of countries reveal that the arithmetic averages of the scores belonging to the digital literacy levels of pre-service teachers in Turkey show a significant difference in all dimensions of the scale compared to pre-service teachers in Kazakhstan. This may be due to the fact that the technology infrastructure in Turkey is more developed than in Kazakhstan and the application environments of the teaching programmes are more convenient.

In the research conducted, the integration of digital technologies into education stands out as one of the most important educational issues not only today but also in the future. The issues such as the development of digital literacy skills, effective use of technology in pedagogical practices, the need for practical training and teachers' openness to innovations emphasised in the participant views reveal the current steps that need to be taken to increase the effectiveness of technology in education. In the research conducted by Ally (2019), it is predicted that Fourth Industrial Revolution elements such as artificial intelligence, robotics and the internet of things will be integrated into teaching processes, and even hybrid models in which robot teachers and human teachers will work together may develop. In this framework, teacher education programmes need to be restructured with a holistic and innovative perspective towards future educational environments, not only focusing on overcoming current deficiencies.

The development of literacy skills in education is critical for teachers and students. In the related literature, it is emphasised that technical skills are generally prioritised in studies on the development of digital competencies (Instefjord, 2015). In the data, it is seen that the need to improve teachers' digital literacy skills is high in frequency. This shows that teachers' competences should be increased in order to use digital technologies effectively and efficiently.

In the study, pre-service teachers stated that digital literacy was not sufficiently covered in university education and stated that in order to overcome the deficiencies in this field, applied education should be increased, content for media literacy should be added and teacher training programmes should be restructured with a focus on digital competence. Similarly, Botturi's (2019) study in Switzerland showed that even a short-term training positively affected pre-service teachers' awareness, self-efficacy perceptions and classroom practices regarding digital media literacy. These findings reveal the importance of addressing digital literacy skills in a systematic and practical way in teacher training programmes. Considering that teachers are the people who will contribute to the development of digital literacy skills, it can be said that faculties of education should be adequate and equipped to provide pre-service teachers with training on these skills (Duran, & Ertan Özen, 2018).

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Computer-Based Interactive Laboratory in Physics Learning: Systematic Literature Review (SLR)

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Abstract: There are numerous types of computer-based interactive laboratories, including virtual simulations and microcomputer labs, that can be applied in physics learning process. The research methodology employed in this literature review study is Systematic Literature Review (SLR) guided by the PRISMA framework. This study encompasses three categories of analysis questions for the articles. The first analysis focuses on the types of laboratories used in physics education. The second analysis examines the learning models used with computer-based interactive laboratories. The third analysis, the potential implementation of computer-based interactive laboratories in physics learning. The research data were collected from the Scopus database with the assistance of the Watase Uake system. The findings of this study address all three categories of analysis questions. The research results show that there are 10 types of virtual simulation laboratories, while there are two types of microcomputer laboratories. Based on the research findings, the implementation of computer-based interactive laboratories indicates that research-based learning models (STEM, PBL, Inquiry, PJBL and Problem Solving) with project and experimental methods are highly suitable for use in the process of computer-based interactive laboratory learning.

Keywords: Interactive learning; computer laboratory; physics microcontroller; simulation-based experiments; Arduino

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Introduction

The 21st century is known as the “digital era” or the “digital society” (Cahya et al., 2023). The skills of the 21st century involve developing teaching improvements, especially collaborative skills, creativity, communication, and critical thinking, and how to develop them within students (Ait El Mokhtar et al., 2023). Teachers play a crucial role in this regard, keeping up with changes. They must be able to inspire, guide, and use information and communication technology efficiently and effectively to enhance students' learning outcomes (Mopara & Sanrattana, 2023).

The use of technology can be implemented in all school learning environments. One of these is physics education, presenting a new challenge to improve teaching quality by achieving better interpretations in both conceptual and experimental aspects (Asencios-Trujillo et al., 2024). Physics is inseparable from experiments and heavily relies on establishing the principles and fundamental laws of the universe (Havlíček, 2015). Experiments are always closely related to theoretical modeling, while the investigation process is always based on the close interaction between experiments and theory (Akimkhanova et al., 2023). To build students' knowledge through experiments with science laboratory activities (Tobin, 1990). Science laboratories can help students acquire knowledge of science if they are engaged in active and successful laboratory activities (Chen et al., 2014).

The information technology and the internet have had a significant impact on transforming science laboratories, leading to the emergence of new forms of laboratories (Castro-Gutiérrez et al., 2021). Experiments based on the web or online experiments, such as virtual laboratories, have a positive impact on students' knowledge, skills, and attitudes. Virtual laboratories refer to interactive computer simulations (Tsvetkova et al., 2024). Microcomputer laboratories are computer-based experiments connected with software and linked to probe devices such as motion sensors, force sensors, voltage sensors, temperature sensors, sound sensors, acceleration sensors, light sensors, charge sensors, rotary motion sensors, and magnetic field sensors (Zakaria et al., 2019). Microcomputer laboratories have proven effective in enhancing students' inquiry skills and conceptual understanding (Rhee & Im, 2018).

Utilizing computer technology for interactive laboratories as a support in physics learning to facilitate understanding of physics in various scopes of physics learning. A systematic literature review research is needed that collects, and analyzes, findings from related studies regarding the types of interactive laboratories that can be used in physics learning. This research aims to conduct a systematic literature review on the identification of interactive learning laboratories that can be used in physics education by analyzing findings from articles published in the last 7 years. This study is a systematic literature review using the PRISMA method. Through this method, it is hoped that new knowledge and insights related to computer-based interactive laboratories in innovative physics learning can be gained.

Method

This study employed the Systematic Literature Review (SLR) methodology, which was a systematic approach used to identify, evaluate, and interpret relevant articles published together with references and specific research questions (Ali et al., 2022). SLR with PRISMA guidelines is a framework designed to address poor systematic reporting (Akimkhanova et al., 2023). S SLR guides the planning of new research to advance knowledge substantially (Paul et al., 2021). Therefore, for the literature review in this study, literature related to the implementation of computer-based interactive laboratories in physics education published as full articles in scientific journals from 2017 to 2024 was studied.

The search strategy plays a crucial role in gathering relevant literature on a specific topic in an efficient manner. This research has stages in the search strategy for gathering literature, inclusion criteria for data processing, and drawing conclusions following previous research (Hariningsih et al., 2024).

The first stage involves collecting literature by first formulating research questions. Three research questions were established.
Q1: What are the types of computer-based interactive laboratories that can be used in physics learning?
Q2: What are the learning models used in implementing computer-based interactive laboratories in the process of physics learning?
Q3: What is the potential of implementing computer-based interactive laboratories in physics learning?

Next, literature studies were conducted. All article data reviewed were accessed on the Scopus database. This was done to focus the review on one database. The Scopus database was chosen as the main option because it is one of the largest scientific literature databases in the world. Scopus article searches were performed on the official Scopus website with the assistance of the Watase Uake system. Watase Uake is a systematic literature review tool that can map a specific theme of articles and conduct in-depth analysis. It identifies keywords, criteria, and limitations. In the search section, the following keyword combinations were used.

- For virtual simulation laboratories, the following keywords were used: "physics" AND "learning" AND "interactive" OR "physics" AND "learning" AND "virtual physics simulation laboratory" OR "physics" AND "experiment" AND "computer simulation".
- For microcomputer laboratories, the following keywords were used: "physics" AND "learning" AND "microcomputer" OR "physics" AND "learning" AND "microcontroller physics laboratory" OR "physics" AND "experiment" AND "arduino".

Stage two involves setting inclusion and exclusion criteria. Setting inclusion criteria is used to limit or create a strategy regarding the suitability of articles with the topic criteria being researched. Articles that are included or excluded for analysis are based on the inclusion criteria displayed in Table 1.

Table 1. Criteria for Inclusion used in selecting articles

Criteria	Meaning
Conceptual Understanding in Physics	Research related to understanding concepts in physics subjects.
"Computer-Based Interactive Laboratories"	Research showing interactive learning activities when using laboratories.
Time Interval	The article search is focused on articles published between 2017 and 2024.
The subject area of the search.	Article search is limited to the fields of physics and computing.
Document type	Development articles, application articles, and conferences

The exclusion criteria for this study are unclear physics-related research on computer-based laboratories and their applications. Studies that are inaccessible or not closely related to the topic being discussed are also excluded.

The number of articles obtained from the Watase Uake system is 198 articles. A manual search on the Scopus database yielded 32 articles. In total, there were 230 articles. After applying a time constraint of 7 years on the Watase Uake system, 132 articles were obtained. After reading the titles, abstracts, and keywords of selected articles, 56 articles were excluded for not meeting the inclusion criteria, resulting in 76 articles. Further scrutiny led to 58 articles meeting the criteria. An analysis of classification, discussion, and conclusion yielded 34 articles. This filtering and assessment resulted in 34 articles.

In the third stage of the literature review process, literature obtained from inclusion and exclusion criteria data was reviewed and intensively examined one by one. After thorough reading and understanding, 18 articles were removed because the physics content did not specifically address the research questions to be answered, and some articles were inaccessible. Thus, a total of 34 articles were identified and included in this research data. An overview of the entire filtering and assessment process is further explained in Figure 1.

Stage four, data presentation and data processing. In this stage, the results and discussion regarding computer-based interactive laboratories will be structured and divided into two classifications. The first laboratory is a virtual simulation laboratory. The second laboratory is a microcomputer laboratory. Next, the categorization of laboratory types will be identified within these two classifications of computer-based interactive laboratories. Finally, conclusions will be drawn to answer the established research questions.

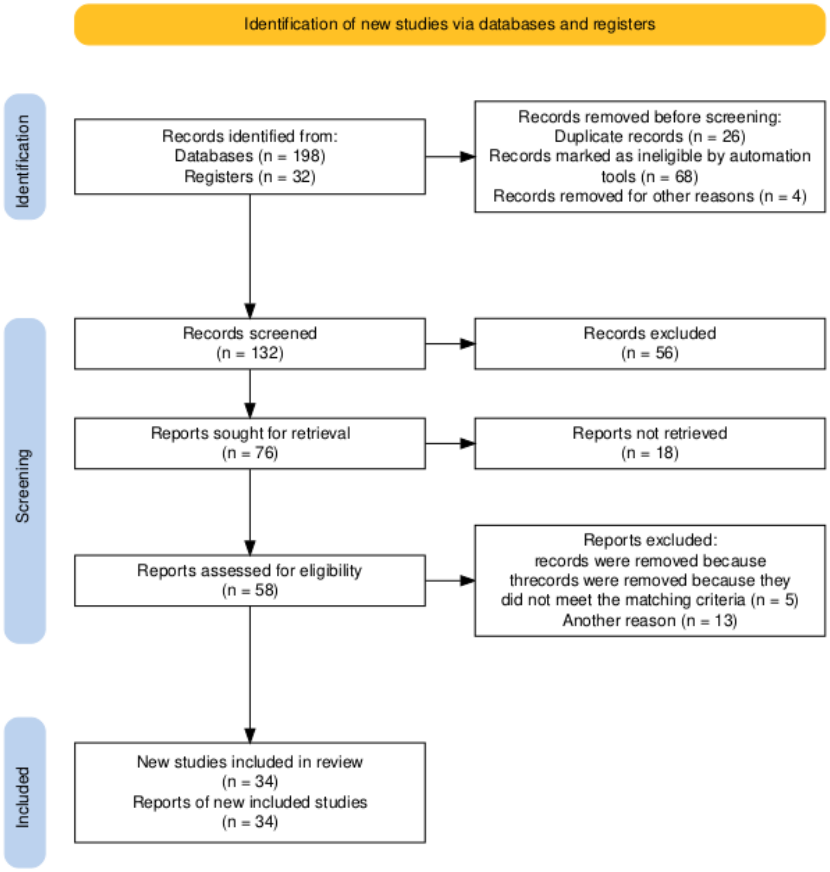

Figure 1. The research methodology includes the search strategy, article selection criteria, quality assessment, and data extraction.

Results and Discussion

What are the types of computer-based interactive laboratories that can be used in physics education?

Computer-based interactive laboratories are one of the efforts made to help students understand specific topics in physics. In this research, they are classified into two categories: virtual simulation laboratories and microcomputer laboratories. The explanation of these two types of laboratories is presented in Table 2 and Table 3. Table 2 describes the types of virtual simulation laboratories and the findings developed for use in physics education. Table 3 explains the types of microcomputer laboratories and the findings developed for use in physics education.

Virtual Simulation Laboratories

Table 2.

No	Authors	Physics Materials, Testing, and Countries	Types of Virtual Simulation	Findings

			Laboratories	
1.	(Rosdiana et al., 2019)	Kirchhoff's Law, High School Students, Indonesia	*Virtual Physics Laboratory (ViPhyLab)*	The development study of the Virtual Physics Laboratory (ViPhyLab) was conducted using Adobe Flash Professional CS6 software. ViPhyLab can be used as an alternative when conducting Kirchhoff's law material experiments is not feasible to assist in explaining the concept of material and practical skills for students.
2.	(Korlat et al., 2024)	Electricity, Junior High School Students, England	*PhyLab*	The development research of PhysLab was conducted using 3D game technology. This simulation is classified according to supporting theories and scenarios. The results of this research show that the simulation can be effectively used in the classroom to explain physics concepts in teaching and experiments.
3.	(Hamamous & Benjelloun, 2022) (Software Crocodile Physics, n.d.)	Electricity, Second Year Junior High School Students, Morocco	*Crocodile physics*	Research on the application of physics learning with an inquiry-based model using the experimental method with Crocodile Physics was conducted. The results of this research improved the understanding of new concepts in physics learning, especially in electricity.
4.	(Dewi et al., 2022)	"RLC series circuit, junior high students, Indonesia"	*Crocodile physics*	Research on application and development. This study creates an interactive inquiry E-module with the help of Golabz and

	(Software Go-Lab, n.d.)			connects it with the Crocodile Physics virtual simulation laboratory as a practical tool. This research aids students in understanding RLC circuit material.
5.	(Rahmi et al., 2022)	Temperature and Heat, Junior High School Students, Indonesia	STEM-Based Virtual Laboratory	The research developed a virtual laboratory based on the STEM approach. The results of this study can reduce misconceptions of physics concepts, effective use of time and interactive learning.
7.	(Euler et al., 2020)	Newtonian Mechanics, University Student, Sweden	*Algodoo*	Application research. In this study, the Algodoo virtual simulation laboratory was used for 2D Newtonian mechanics (friction coefficient, spring constant with variation theory model, and gravity). The results of this research can help students think creatively and be motivated in learning physics.
	(Software Algodoo, n.d.)			
8.	(Çoban, 2021)	Momentum and Impulse, High School Students, Turkey	*Algodoo*	Research on the application of the Algodoo virtual simulation laboratory for momentum and impulse material can be used in online learning, improving teaching efficiency and students' active participation in learning.
9.	(Ibrahim et al., 2024)	Newton's Laws of Motion, University	*Algodoo*	Research on the development of the Pantograft-catenary model 9DOF, which can be used for

		Students, Malaysia		vertical direction analysis and experimental approaches with MATLAB/Simulink and the 2D simulation software Algodoo.
10.	(Bouchée et al., 2024) (Software PhET, n.d.)	Quantum Physics (Particle in a Box), High School Students, Netherlands	*PhET*	Research on the application of the PhET virtual simulation laboratory can be used by creating worksheets that combine inquiry-based learning. Students can work independently with interactive simulations, enhancing their conceptual understanding of the particle in a box topic.
11.	(Banda & Nzabahimana, 2023)	Oscillations and Waves, Junior High School Students, Africa	*PhET*	Research on the application of PhET in physics learning can improve learners' motivation and academic achievement in isolation and waves in Malawi. PhET is an affordable and efficient experimental simulation alternative for schools in socio-economically deprived countries such as African countries.
12.	(De Oliveira Almeida & Bastos, 2018)	Oscillation of a pendulum, High School, Brazil	*PhET*	Research on the implementation of PhET with the Theory of Learning Variations (contrast, variation dimension, and relevance structure) in the Problem-Solving model using the demonstration method. The results of this study suggest using the interface for high school students. The research also found that PhET can improve students' understanding of concepts.

13.	(Nasirov & Xudoyeva, 2023)	Physics of atoms and nuclei (Rutherford), High School, Uzbekistan	*PhET*	The research applied PhET before testing by teachers. Afterward, it was tested with students. The experiments were conducted using the experimental method. The results of the students' experiments enabled them to observe material that is difficult to visualize and improved their understanding of concepts.
14.	(Yuliati et al., 2018)	Direct current electricity, University Student, Indonesia	*PhET*	The study applied the inquiry learning model along with a mixed method and experimental approach. The research found that PhET influenced students' problem-solving abilities and improved their understanding of concepts.
15.	(Castro-Gutiérrez et al., 2021)	Optics, University Students, Marocco	*Easy Java Script Simulasi (EJSS)*	This research is a development study of a laboratory using JavaScript programming. The laboratory development is carried out by universities in Morocco with the assistance of European partners and implemented in 12 science faculties. The target of the laboratory can be evaluated by teachers and students. The results obtained have a positive impact in improving conceptual understanding, scientific achievement, and skills. Additionally, it can be used as an alternative to physics laboratories.

16.	(Swandi et al., 2020)	Wave-Particle Duality, University Students, Indonesia	*TEALSim*	The research focused on the application of TEALSim through experimental methods. The results of this study showed that students were able to understand abstract concepts and analytical skills, leading to an improvement in their understanding of concepts.
17.	(Aşiksoy & Islek, 2017)	Ohm's Law, parallel and series resistor relationships, Kirchhoff's Laws, and Magnetic Fields, University Students, Turkey	*Circuit lab Sofware*	The research focused on the application of Circuit Lab Software, which was tested with students to assess its implementation in learning. The results indicated that the Circuit Lab Software laboratory had a positive impact. This was achieved through their experimental method, where they conducted experiments themselves following the existing procedures.
18.	(Chawda, N., et al., 2019)	Nuclear Physics, University Students, Serbia	*Virtual reality (VR)*	The research focuses on the application of Virtual Reality (VR) in experimental methods. Preparation is done with experimental data (gamma spectra) and specific results will be extracted from this experiment. This research uses virtual reality techniques to conduct experiments. Participants can visualize 3D objects they observe, such as particles. This is done to familiarize students with real laboratories.

19.	(Pirker et al., 2017)	Electromagnetics, High School, Austria	*Virtual reality (VR)*	The research focused on the implementation and development of Virtual Reality (VR) with STEM modeling. The type of Virtual Reality (VR) used was Samsung Gear VR connected to Samsung S6. The results of this research showed that students gained engaging direct experiences, serving as a complement to classroom learning models.
21.	(Erdoğan & Bozkurt, 2022)	Geometric Optics, University Students, Turkey	*Easy Java Script Simulasi (EJSS)*	The development research of the laboratory was conducted using Java Script. The language used for explanations or instructions in the simulation was Turkish. The simulation included "Thin Lens" and the formation of images on mirrors. The results showed that students were able to understand each concept taught.

Based on the analysis of articles from 2017 to 2024, it can be seen that there are various virtual simulation laboratories that can be used in physics education. Educators can also develop different types of laboratories using various methods as outlined in the table. The analysis was carried out to review the most frequently implemented and developed laboratory profit in physics learning. Displayed in Table 3 and depicted in the form of a graph in order to facilitate reading and analysis shown in Figure 2.

Table 3. Representation of types of virtual simulation laboratories.

Types of virtual simulation laboratories	Authors	Quantity
Virtual Physics Laboratory (ViPhyLab)	(Rosdiana et al., 2019)	1
PhyLab	(Korlat et al., 2024)	1
Crocodile physics	(Hamamous & Benjelloun, 2022) (Dewi et al., 2022)	2

STEM-Based Virtual Lab	(Rahmi et al., 2022)	1
Algodoo	(Euler et al., 2020) (Çoban, 2021) (Ibrahim et al., 2024)	3
PhET	(Bouchée et al., 2024) (Banda & Nzabahimana, 2023) (De Oliveira Almeida & Bastos, 2018) (Nasirov & Xudoyeva, 2023) (Yuliati et al., 2018)	6
Easy Java Script Simulasi (EJSS)	(Erdoğan & Bozkurt, 2022)	2
Circuit lab Sofware	(Aşiksoy & Islek, 2017)	1
Virtual reality (VR)	(Chawda, N., et al., 2019) (Pirker et al., 2017)	2
TEALSim	(Swandi et al., 2020)	1

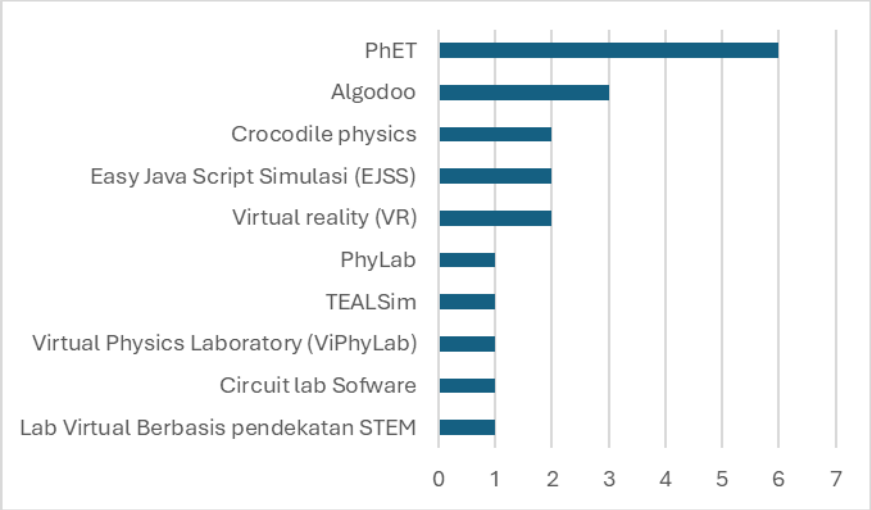

Figure 2. Representation of virtual simulation laboratories

From the analysis of the table and its graphical representation, it was found that there are 10 types of virtual simulation laboratories. The total number of laboratories found is 21, as some articles used more than one virtual simulation laboratory. Based on the analysis, the most widely used type of virtual simulation laboratory in this research is PhET. PhET is more commonly used for several reasons and is supported by previous studies. PhET has achieved global acceptance due to its simplicity, versatility, and free online availability (Tuyizere &

Yadav, 2023). PhET provides an open and standards-based technology infrastructure, primarily consisting of HTML5, JavaScript, and CSS. PhET based on specific natural laws (gravity, net force, buoyancy, etc.) or scientifically defined concepts (density, area, pressure, mass, etc.) coded into programming. Participants only need to manipulate various parameters (Llorella et al., 2024). PhET enables learners to demonstrate model representations with real-world occurrences. This makes it easier for learners to visualize something challenging to visualize, such as particles (Nasirov & Xudoyeva, 2023). Students can directly manipulate initial conditions and observe their impacts (Ng & Chua, 2023). PhET is integrated into the classroom for experiments and demonstrations in the physics learning process (Tuyizere & Yadav, 2023). The implementation results in the physics learning process can improve students' conceptual understanding to a higher level (Susilawati et al., 2022).

Microcomputer Laboratory

Table 4.

No	Authors	Materi, Uji Coba, dan Negara	Types of Microcomputer Laboratories	Findings
1.	(Liu et al., 2017)	Kinematics, High School Students, Taiwan	*Microcomputer Based Laboratory MBL)*	The development and application research on Microcomputer-Based Laboratory (MBL) with experimental methods are enhanced by the integration of new technologies. Smartphones are used across all laboratories, digital video recorders are used in free fall motion experiments, and Lego Mindstorms NXT is used in pendulum and inclined motion experiments. The results show that students acquire direct experimental skills, learn how to measure and analyze large amounts of data, are able to independently solve problems, collaborate with peers to solve problems in the laboratory, and increase their motivation to learn.

2.	(Antwi et al., 2018)	Graph of Kinematics (Displacement, Velocity, and Acceleration), University Students, Netherlands	*Microcomputer Based Laboratory (MBL)*	The development and application research of Microcomputer-Based Laboratory (MBL) using the Coach 6 sensor (motion sensor) can be interactively used to easily and quickly create graphs on the computer by capturing the physical movement of an object, converting position-time graphs to velocity-time graphs and acceleration-time graphs. The results obtained from this research show that students improve their experimental skills.
3.	(Rhee & Im, 2018)	Physics, University Students Korea Selatan	*Microcomputer Based Laboratory (MBL)*	The development and application research of Microcomputer-Based Laboratory (MBL) using sensors as replacements for measuring devices to collect data and convert it into digital data, which is then sent to a computer, has advantages in terms of accuracy of recording and ease of data storage.
4.	(Zakaria et al., 2019)	Newton's Laws, High School Students, Malaysia	*Mobile Computer Based Physics Laboratory (MCPL)*	The development and application research on Mobile Computer Based Physics Laboratory (MCPL), a combination of Mobile Science Laboratory (MSL) and Microcomputer Based Laboratory (MBL), can connect Newton's laws content with real-world representations through inquiry-based learning modeling. The results of this research include improving students' conceptual understanding and experimental

				skills, as well as enhancing learning motivation.
5.	(Villarino, 2019)	Force and Motion, Junior High School Students, Philippines	*Microcomputer Based Laboratory (MBL)*	The research on the development and application of Microcomputer Based Laboratory (MBL) combined with the constructivist strategy (CS) and traditional strategy (TS). The results showed that the constructivist strategy (CS) with Microcomputer Based Laboratory (MBL) can improve students' conceptual understanding compared to the traditional strategy (TS).
6.	(Erol & Kuzucu, 2024)	Heat, High School Students, Turkey	*Arduino*	The study focuses on the development of Arduino with the DS18B20 temperature sensor, used in physics experiments to measure and teach the concept of heat.
7.	(Cicuta & Organtini, 2024)	Electricity (Ampere's Law), High School Students, England	*Arduino*	The research involves the development and application of Arduino in angular pendulum (harmonic oscillation) material, both theoretically and experimentally, using the gypro sensor (MPU6050) and Bluetooth for STEM education. The results obtained aim to enhance students' understanding, improve skills, and conceptual understanding.
8.	(Marín-Marín et al., 2024)	Physics and Mathematics, Junior High School Students, Spain	*Arduino*	The research and development of Arduino with LED lights, servo motors, and a whiteboard in formal education aim to enhance students' programming skills and

				computational thinking. It also aims to develop STEM projects in physics and mathematics lessons.
9.	(Hahn et al., 2024)	Physics, High School Students, Portugal	*Arduino*	Research on the development and implementation of Arduino with LED lights utilized the Arduino platform to manipulate lights, motors, and other actuators while simultaneously collecting data from various sensors. The implementation was carried out using the STEM learning model. Students were able to understand the addition of colors through two different mechanisms: colors displayed on the screen and colors on the Arduino board.
10.	(Spaan & Stevens, 2022)	Nuclear Physics, University Students, Germany	*Arduino*	Research on the development and implementation of Arduino is being conducted with specific front-end electronic devices to calculate proportional readings with pulse shape analysis. This research aims to provide a cost-effective alternative for various applications ranging from student projects to small-scale instruments. It is implemented in a Problem-Based Learning (PJBL) model of teaching and learning.
11.	(Çoban & Çoban, 2020)	Sound Waves, High School Students, Turkey	*Arduino*	Research on the development and implementation of Arduino with the AR-054 sound sensor and green LED in a project-based STEM learning model. The

				results of this study show that Arduino is very useful for preparing 21st-century learning skills, providing students with an affordable way to conduct experiments.
12.	(Chaudry, 2020)	Physics (mechanics, electricity and magnetism, light and optics), High School Students, United States	*Arduino*	Research on the development and implementation of Arduino with various sensors in student-conducted STEM project-based learning models. The results obtained increased students' interest in physics and helped them understand several basic physics concepts.
13.	(Gfroerer et al., 2022)	Electricity, High School Students and University Students, United States	*Arduino*	Research on the development and implementation of Arduino with several sensors. In this study, the STEM learning model involved students learning to create a simple circuit to control the temperature in a solar-powered model building.

Apart from virtual simulation laboratories, other types of computer-based laboratories were analyzed, including microcomputer laboratories. Based on the analysis of articles from 2017 to 2024, various microcomputer laboratories suitable for physics education were identified. Educators can also develop various laboratories using different methods as outlined in the table. An analysis was conducted to review the most frequently implemented and developed laboratories in physics education. This is displayed in Table 4 and depicted graphically in Figure 3 for easier reading and analysis.

Table 4. Representation of types of microcomputer laboratories

Types of Microcomputer Laboratories	Authors	Quantity
Microcomputer Based Laboratory MBL)	(Liu et al., 2017) (Antwi et al., 2018) (Rhee & Im, 2018) (Zakaria	**5**

	et al., 2019) (Villarino, 2019)	
Arduino	(Erol & Kuzucu, 2024) (Cicuta & Organtini, 2024) (Marín-Marín et al., 2024) (Hahn et al., 2024) (Spaan & Stevens, 2022) (Çoban & Çoban, 2020) (Chaudry, 2020) (Gfroerer et al., 2022)	**8**

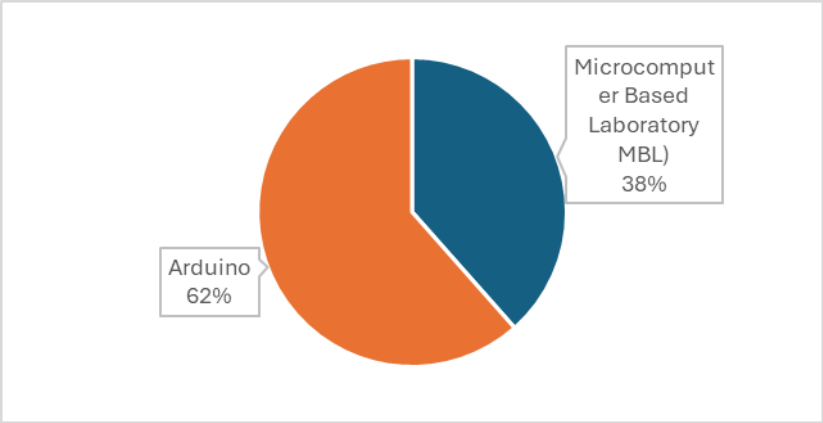

Figure 4. Representation of types of microcomputer laboratories

The results of the literature review study are presented in Table 4 and Figure 4. Based on the data analysis, two types of microcomputer-based laboratories were identified from 2017 to 2024. A total of 13 articles were found on microcomputer-based laboratories, indicating their development and application in physics education. It would be interesting to conduct a more in-depth review focusing specifically on the years 2017 to 2019 to gain further insights from the data. Further research was conducted on Scopus, revealing that research on Microcomputer-Based Laboratory (MBL) ceased in the year 2022. The results are displayed in Figure 5.

Based on another analysis, it was found that Arduino is the most widely used with a percentage of 62%. Arduino obtains the highest percentage for several reasons. Arduino, along with attachable sensors, can be obtained at an affordable price (Schnider & Hömöstrei, 2024). Arduino is based on a combination of software and hardware. Arduino can be developed in processing information, text, sound, and numeric like those developed with handheld devices or smartphones. Arduino can be used as a teaching strategy to help students in recording and obtaining data in the form of images, graphs, and diagrams, as well as communicating mathematical, physical, and chemical equations (Gomes et al., 2020). Arduino is explored experimentally in the learning process, allowing students to delve directly into more complex scenarios using principles of electronics, sensors, and instrumentation (Cicuta & Organtini, 2024). Arduino is used in curricula for developing programming skills and computational thinking in the context of formal education applied by many education systems worldwide. Arduino is particularly used in technology and physics subjects and is used to develop

project-based I (Marín-Marín et al., 2024). When presenting project activities, students seem to be playing a cognitive game, where they learn many important scientific ideas and develop direct skills needed in the future. It enables students to enhance interest and develop basic competencies in robotics (Gomes et al., 2022). Overall, integrating robotics in the educational environment can spark interest in STEM topics and deeper engagement in complex concepts, as well as engage students in critical thinking and problem-solving in teams (Anwar et al., 2019).

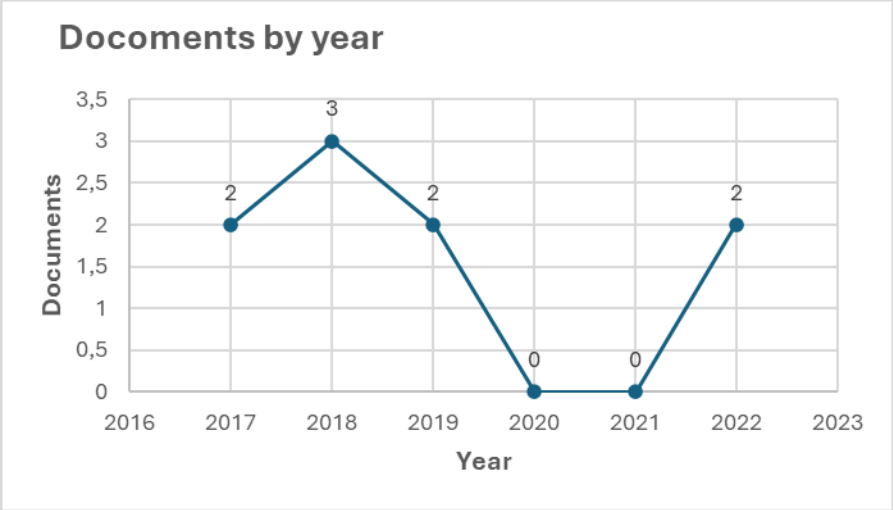

Figure 5. Data from Scopus research on Microcomputer-Based Laboratories (MBL)

What are the learning models used in the implementation of computer-based interactive laboratories in the process of physics learning?

Table 5.

Learning Models	Authors	Quantity
PJBL	(Spaan & Stevens, 2022)	1
Problem Solving	(Spaan & Stevens, 2022)	1
Variation Theory	(Euler et al., 2020)	1
Inquiry	(Hamamous & Benjelloun, 2022) (Dewi et al., 2022) (Bouchée et al., 2024) (Yuliati et al., 2018) (Zakaria et al., 2019)	5

STEM	(Rahmi et al., 2022) (Cicuta & Organtini, 2024) (Marín-Marín et al., 2024) (Hahn et al., 2024) (Çoban & Çoban, 2020) (Chaudry, 2020) (Gfroerer et al., 2022)	6

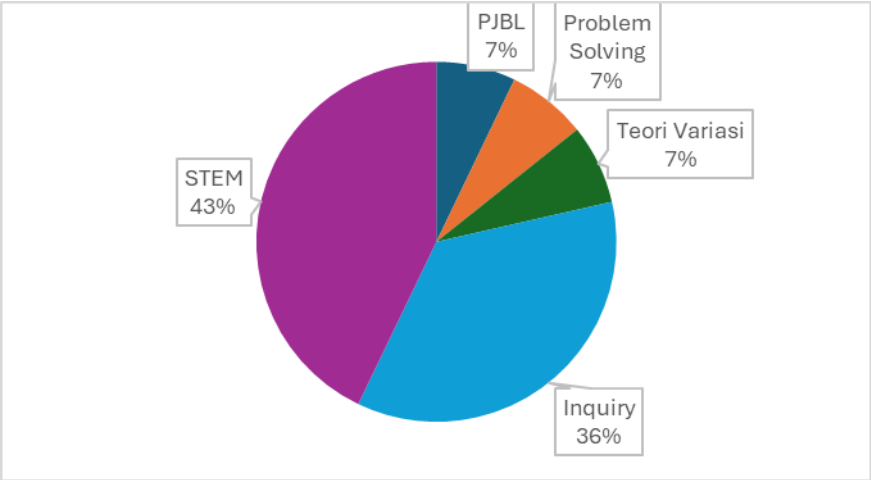

Figure 6. Learning Models

The results of the literature review study on computer-based interactive laboratories are categorized into two classifications: virtual simulation laboratories and microcomputer laboratories within the physics learning model. The results are presented in Table 5 and Figure 6, which show that the most widely used learning model is the STEM learning model, with a percentage of 43%. Other learning models include Inquiry at 36%, and PJBL and Problem Solving at 7%. In line with the analysis, the frequently used learning model is the scientific research learning model, which is often combined with experimental, demonstration, or project methods. For further explanation of the learning models used in this study, several definitions from previous research are provided. Education in Science, Technology, Engineering, and Mathematics (STEM) is emphasized. The implementation of computer-based interactive laboratories with STEM in project-based methods is very promising because it establishes the relevance and research nature of the project topics, ensures the connection between theoretical knowledge and practice, and applies practical results (Ball et al., 2017; Ministry of Education, 2023). Moreover, STEM education may involve hands-on, project-based learning, which can be more engaging and motivating for students compared to traditional rote learning methods. The use of interactive tools and technologies in STEM education, such as computer-based interactive laboratories, can enhance student engagement, motivation, and literacy (Ismail et al., 2016). The Inquiry learning model is an instructional approach where students solve problems using specific procedures. The experimental method can be utilized within the Inquiry model for implementing computer-based interactive laboratories (Simbolon & Silalahi, 2023). The Project-Based Learning (PjBL) model uses projects as a medium to introduce students to realistic experimental physics (Bouquet et al., 2017). The Problem-Solving model with computer-based interactive laboratories supports easier problem solving and enables students to define and explain laws and theories

through hands-on activities. Problem-solving in physics is a very challenging task because it involves abstract concepts (Pal & Rinki, 2022).

What is the potential contribution of computer-based interactive laboratories in physics learning?

Based on the results from tables 2 and 3 above, various types of computer-based interactive laboratories are used in physics learning. Out of the 34 articles reviewed, 30 articles highlighted the potential contribution of computer-based interactive laboratories in physics education, specifically in improving students' conceptual understanding as mentioned in 30 articles. Additionally, research (Rahmi et al., 2022) suggests that computer-based interactive laboratories can reduce misconceptions of physics concepts and are highly effective for interactive learning. Similar research (Pirker et al., 2017) suggests that using computer-based interactive laboratories provides students with engaging direct experiences and can be used as a supplement in classroom learning models. According to his laboratory (Banda & Nzabahimana, 2023) is affordable and efficient for schools in countries with lower socio-economic status, such as African countries (Banda & Nzabahimana, 2023). Another opinion (Chaudry, 2020) from states that the use of interactive laboratories in the learning process is aimed at preparing 21st-century learning skills for students in conducting affordable experiments, and fostering students' interest in physics. These indicate a strong emphasis on the role of interactive laboratories in enhancing students' understanding of physics concepts. This suggests that computer-based interactive labs are particularly effective in making abstract or complex concepts more accessible and comprehensible (Ali et al., 2022). The interactive and visual nature of these tools likely facilitates better cognitive processing and retention of information. This may contribute to increased student interest and motivation to learn (Simões et al., 2022). This is crucial as motivated students are more likely to engage deeply with the material and persist through challenges. The significant impact on skill improvement underscores the practical benefits of these tools in providing hands-on, experiential learning opportunities. However, the relatively low impact on science achievement and reduction of misconceptions indicates areas where further research and development are needed. It might be beneficial to explore how interactive labs can be better integrated with assessment tools and corrective feedback mechanisms to enhance these outcomes (Appelgren & Lascarides, 2020).

Conclusion

In this research, a literature review study on computer-based interactive laboratories in physics education was conducted. A total of 34 articles were selected through the SLR method guided by PRISMA. The 34 articles in this study are divided into two classifications: virtual simulation laboratories 21 articles and microcomputer laboratories 13 articles. From the review of these 34 articles, several types of virtual simulation laboratories were identified, including Virtual Physics Laboratory (ViPhyLab), PhyLab, Crocodile Physics, STEM-based Virtual Laboratory, Algodoo, PhET, Easy Java Script Simulation (EJSS), Circuit Lab Software, Virtual Reality (VR), and TEALSim. The most commonly used virtual simulation laboratory is PhET. Microcomputer laboratories consist of two types: microcomputers and Arduino. The implementation of these computer-based interactive laboratories, according to research findings, shows that scientific learning models (STEM, Project-

Based Learning (PjBL), Inquiry, and Problem Solving) with project and experimental methods are highly suitable for use in computer-based interactive laboratory learning processes. Furthermore, the results of applying these laboratories in physics learning processes have proven that they can enhance students' conceptual understanding and motivation in learning physics. Not only that, but students also experience direct and engaging hands-on experiences, reduce misconceptions in physics concepts, and foster students' interest in physics.

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