ENHANCING STEM EDUCATION THROUGH STEM LEADERSHIP PRACTICES: A FUZZY DELPHI METHOD APPROACH

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ABSTRACT

Using the fuzzy Delphi method, this study aims to obtain expert agreement on the elements of school leaders' practices that influence student learning and teacher effectiveness in strengthening STEM instructions. An instrument on STEM leadership was presented to a total of 26 experts in STEM-related fields. The results of this study show that the expert panel agreed with the proposed constructs and elements of school leaders' practices that influence student learning and teacher effectiveness in STEM. The practices tested in the study also met the conditions specified in the fuzzy Delphi method, namely, a threshold value (d) greater than 0.2 (d > 0.2), experts' agreement greater than 75% with values ranging from 81% to 96% agreement, and a fuzzy score value (A) greater than 0.5 (A ≥ 0.5) with values ranging from 0.865 to 0.918. The defuzzification process used by the fuzzy Delphi method also reorders all items by priority based on expert consensus. Of all the elements agreed upon by the experts, the element that ranked highest in the construct of student learning is related to the leader's emphasis on hands-on activities through problem-based learning/project-based learning (PBL) in improving student skills. The element that ranks highest in the construct of teacher effectiveness is related to the leader's ability to promote innovation in teaching to enhance the quality of STEM learning.

Keywords: *STEM education, student learning, teacher effectiveness, STEM leadership, fuzzy Delphi method*

INTRODUCTION

STEM education is an interdisciplinary approach that integrates science, technology, engineering, and mathematics into a cohesive learning paradigm based on real-world applications. STEM education aims to cultivate students' creativity, problem-solving ability, and critical thinking skills. The discussion of STEM education has been spread nationwide and has impacted the building of knowledge, skills, and understanding in the education system. The analysis of STEM education as a contemporary social and cultural phenomenon revealed its importance for current education in the society of innovation and information (Freeman et al., 2019; Xie et al., 2015).

In particular, the definition of "STEM education" varies greatly depending on the level of education (Breiner et al., 2012). STEM education at the elementary school level centers on active involvement in science and mathematics. As the curriculum advances to more specialized tiers of learning, the concept of STEM education becomes progressively more refined (Xie et al., 2015). Additionally, STEM education helps students develop a growth mindset, perseverance, and an understanding of the iterative problem-solving process. STEM encourages collaboration and teamwork and allows learners to experience hands-on, project-based learning, which can increase engagement and improve retention. Furthermore, STEM education can also enhance digital literacy and familiarity with technology, which are increasingly important in today's world. Overall, STEM education plays a crucial role in equipping students with the necessary skills to excel in the ever-evolving global scenario and triumph in their forthcoming endeavors. The current surge in technology, innovation, and industry is momentarily influencing STEM education and pedagogy. Improving instructional programs considers two main things: helping student learning and engagement and improving teacher effectiveness (Newmann et al., 2001) to encourage student achievement. Consequently, strengthening STEM instructional strategies has become a foremost objective in education, with endeavors concentrated on the professional development of teachers and the enhancement of curricular content, which ultimately affect students' learning outcomes in STEM disciplines (Lynch et al., 2019).

Investing in sustained professional development holds significant potential in promoting reform within the STEM field. By enhancing teachers' knowledge, comprehension, and instructional practices, professional training generates a constructive impact on the meaningful learning experience of their students (Salbiah Mohamad Hasim et al., 2022). Therefore, educational institutions must prioritize funding and resources toward providing STEM teachers with professional development opportunities to ensure they have the necessary tools and skills to engage and inspire their students. Moreover, using modern instructional practices by teachers is crucial in providing students with a well-rounded education that prepares them for the digital age workforce (Affandi et al., 2022). These practices include project-based learning, interactive tools and resources, and hands-on experiences that encourage student curiosity in STEM fields. With sustained professional development, teachers can ensure that students receive quality STEM education that meets the demands of the 21st-century workforce.

Furthermore, teaching methods that prioritize the needs and interests of students, such as implementing an engineering design process, can foster self-reliance, analytical reasoning, and effective communication abilities among learners. Recently, there has been an increasing fascination with crafting instructional materials and strategies that facilitate design-led education (Zhou et al., 2020). This type of education framework revolves around design thinking as the core element of the learning journey. It combines inventiveness, exploration, and resolution skills to cultivate innovative solutions to practical predicaments (Wright & Wrigley, 2019). The ultimate aim of design-led education is to produce students who possess not only in-depth knowledge of a particular subject, but also possess the ability to think imaginatively and generate fresh concepts.

Coinciding with these interests, leaders hold the role of instructional leaders responsible for supporting teachers to continue learning and dare to implement new instructional routines and practices (Rigby et al., 2019). Effective leadership in STEM education is essential for teachers to implement STEM approaches successfully. Since teachers have a more significant influence on student learning, leaders need to ensure that the structure and culture that improve teacher quality should be at a reasonable level (Moos et al., 2011) . Therefore, school leaders need to take a holistic approach to education and consider related variables such as learning environment, students' motivation, and the quality of instruction when developing strategies to strengthen STEM instruction.

Student Learning

Student learning is the process by which students acquire knowledge, abilities, and attitudes using a variety of techniques, including instruction, study, experimentation, observation, and practice. The learning environment (Anderson, 2018; Brooks, 2011; Taub et al., 2020), the learner's motivation and interest (Freina & Ott, 2015; Mesa & Lande, 2014; Saari, 2013), and the calibre of instruction (Nur Farhana Ramli & Othman Talib, 2017; Qadach et al., 2020; Song, 2017) are just a few of the variables that might affect learning, which is a lifetime process that occurs both inside and outside of the classroom.

Effective STEM learning happens when students are actively engaged in the learning process. Through active learning, students can engage in interactive activities, collaborate with their peers, and apply what they have learned to actual circumstances (Freeman et al., 2014; Hernández-de-Menéndez et al., 2019). These exercises encourage critical thinking and improve information retention in science.

Vygotsky's theory emphasizes that students' optimal learning happens when they are in their zone of proximal development (Marginson & Dang, 2017). Thus, teachers can enhance learning by providing scaffolded instruction, feedback, and chances for social interaction. Moreover, teachers need to acknowledge the different learning styles of students and offer accommodations accordingly. While certain students may benefit from visual or auditory learning methods, others prefer hands-on experiences (Pashler et al., 2009). Therefore, it is crucial to utilize various teaching strategies and techniques that cater to diverse learning styles to enable students to learn to their fullest potential (Kariippanon et al., 2020). In order to attain the intended results, student learning is a continuous process that needs the assistance of instructors, parents, and the educational community.

STEM Teacher Effectiveness

The impact of teachers on their students' academic achievements and progress is undeniable, highlighting their superior efficacy in promoting favorable educational results. Teacher effectiveness refers to the ability of a teacher to perform their role with perfection, efficiency, and productivity (Saka & Onanuga, 2019). While, Bardach and Klassen (2020) defined it as the impact of exceptional instruction on student learning with regard to advancements in achievement. STEM teacher effectiveness can be evaluated through a multitude of dimensions, including both traditional factors such as education and experience, as well as more unique indicators like instructional content and readiness to teach (Burroughs et al., 2019). Hargreaves and Fullan (2012) take these ideas further, building on established theories of human capital development with the concept of professional capital in teaching, which is comprised of three elements: human capital (investment in an individual teacher's knowledge and skills), social capital (investment in the relationships among educators and the quality and quantity of interactions that allow them to work productively together as a group) and decisional capital (the wisdom and expertise to make sound judgments about learners that are cultivated over many years).

Besides, teachers' pedagogical competence is also essential for effective teaching (König et al., 2021), involving the development of constructive learning environments (Paone, 2019) and considering learners' thinking skills (Wale & Bishaw, 2020). It is the teacher's responsibility to ensure that the student's basic human skills and culturally established technologies are frequently engaged, enhancing their cognitive abilities (Munna & Kalam, 2021). The impact of teachers' effectiveness on school effectiveness is considerable given that effective teachers contribute to upholding educational standards in schools through their preparation, classroom management, mastery of subjects, and interpersonal communication.

Teacher effectiveness refers to the degree to which they are capable of achieving learning goals and objectives. Effective STEM teachers are able to create a positive learning environment that encourages active engagement and fosters deep understanding, critical thinking, and problem-solving skills among students (Hill & Chin, 2018). However, teachers' effectiveness also depends on factors beyond their control, such as students' motivation, parental involvement, and administrative support (Muijs, 2006). Regardless of these external challenges, highly effective teachers remain committed to their profession by finding creative ways to reach each student and positively impact their lives.

Innovation in teaching can help improve teacher effectiveness by providing them with new and creative methods to engage students and enhance their learning experience in STEM. By incorporating innovative teaching strategies, teachers can create a more dynamic and interactive classroom environment, which can lead to increased student engagement and participation (Guardia et al., 2019). Innovative teaching methods can also help teachers cater to the diverse learning needs of their students, allowing for personalized and differentiated instruction. The use of technology in teaching, such as interactive whiteboards, online resources, and educational apps, can enhance teachers' effectiveness by providing them with tools to deliver content more engagingly and interactively (Sanura Jaya et al., 2022). When STEM teachers embrace innovation in their teaching practices, it can also lead to professional growth and development as they continuously seek new strategies and approaches to improve their instructional methods.

The efficacy of school leaders in enhancing the quality of teaching and learning is intricately linked to their perception of the most effective methods of instructing and comprehending STEM subjects (Hatisaru et al., 2020). When instructional leaders play their roles effectively, teachers will have access to the resources and support needed to enhance their knowledge and skills in STEM education (Aduni Johari et al., 2021; Lilia Halim et al., 2021). Teachers will receive professional development, training, and guidance on incorporating best practices in STEM instruction and assessments, leading to improved instructional quality, enhanced student engagement and understanding, and better outcomes for all students. Moreover, teachers will be supported to make individualized instructional decisions that respond to students' needs and interests in STEM which highlight teacher autonomy in classroom (Wermke et al., 2019). They can incorporate technology and real-world applications of STEM and integrate hands-on, inquiry-based, and project-based learning experiences for the students.

However, there is still a lack of research that captures school leaders' practices on strengthening STEM instruction (Hatisaru et al., 2020; Rangel, 2017). Therefore, this research aims to obtain experts' consensus on school leaders' practices in strengthening STEM instructional programs.

METHODOLOGY

Research Design

This study was conducted using the fuzzy Delphi method to obtain the consensus of the experts regarding the dimensions, constructs, and elements developed for the STEM Leadership Best Practices Profile for Secondary School Leaders in Malaysia. A questionnaire was used as the study instrument to obtain consensus among the selected experts to determine elements for the constructs of (i) student learning and (ii) teacher effectiveness under the dimension of strengthening STEM instructional programs.

The fuzzy Delphi method is a comprehensive improvement of the traditional Delphi method. The Delphi method is widely used in government for forecasting, public policy analysis, and project planning. However, the traditional method can be quite costly, requiring multiple rounds of expert opinion. Nevertheless, Ishikawa (1993)introduced fuzzy set theory to solve these time-consuming problems and address the uncertainty in assigning unique numbers.

This study applies the fuzzy Delphi method to prioritize school leaders' practices to strengthen STEM instructional programs among the constructs mentioned, i.e. (i) student learning and (ii) teacher effectiveness. Moreover, this method is very effective because it relies on the expertise of experts to determine the suitability of elements. Moreover, the fuzzy Delphi method is a statistical technique used to derive valid and reliable conclusions from qualitative information (Bui et al., 2020).

Sampling

This study utilizes purposive sampling, which is appropriate for obtaining predetermined expert consensus. Experts are individuals who have invested in their education, profession, personal growth, and social life to the extent that their peers recognize them as such (Booker & McNamara, 2004). They possess extensive knowledge and expertise in a particular field (Cantrill et al., 1996). In Fuzzy Delphi research, the selection of experts is critical. The study's credibility, validity, and reliability rely on the participation of experts, thus, it is important to choose them carefully (Ramlan Mustapha & Ghazali Darusalam, 2017).

This study involved 26 experts, including school principals, STEM lecturers, MOE officers handling STEM at the ministry level, School Improvement Partner+ (SIP+), School Improvement Specialist Coaches+ (SISC+), and STEM teachers. Most principals selected are actively engaged in STEM model schools as part of the Ministry of Education (MOE) coaching programs. The SIPartners+ play roles in enhancing administration quality, while SISC+ provides expert guidance to subject panels and STEM teachers, enabling them to devise effective interventions. In addition, Malaysian STEM teachers are equipped to teach an extensive array of subjects in the STEM domain, encompassing biology, chemistry, physics, mathematics, and computer science. Precisely, the 26 experts were purposely chosen based on expert criteria suggested by Berliner (2004) and Skulmoski et al. (2007). Table 1 shows the criteria of FDM experts involved.

Table 1

Criteria of experts

Profile		No. of Expert (n=26)
Gender	Male	14
	Female	12
Education Level	First Degree	12
	Master's degree	5
	Doctorate Degree	9
Years of Experience	10 - 14 years	2
	15 - 20 years	8
	> 20 years	16
Position	Principal	9
	MOE Officer	2
	Lecture	4
	SIP+	3
	SISC+	1
	STEM teachers	7

Research Instruments

This study uses a questionnaire as a measuring tool to obtain information and necessary data. The questionnaire has been developed from literature and the experts' interviews conducted with the principals, STEM teachers, STEM leaders and STEM lecturers. A total of 8 measurement items are included in the questionnaire regarding strengthening STEM instruction, which is divided into two constructs: students' learning and teachers' effectiveness.

A 7-point fuzzy linguistic scale, ranging from 'extremely not suitable' to extremely suitable,' was used. Additionally, this research instrument employs a 7-point scale to articulate the value of the fuzzy linguistic scale. The 7-point scale was adopted because the more linguistic variables present, the more detailed the scale becomes (Tsai et al., 2020).

Table 2
The definition of the scale fuzzy number

Scale	Linguistic Variable	Fuzzy Scale
7	Extremely agree	(0.9, 0.9, 1.0)
6	Highly agree	(0.5, 0.7, 0.9)
5	Agree	(0.3, 0.5, 0.7)
4	Fairly agree	(0.1, 0.3, 0.5)
3	Disagree	(0.0, 0.1, 0.3)
2	Highly disagree	(0.0, 0.0, 0.1)
1	Extremely disagree	(0.0, 0.0, 0.0)

FINDINGS

The findings of this study refers to the fuzzy Delphi analysis method. Data analysis for the fuzzy Delphi method is based on the threshold value (d), the percentage of expert agreement, and the fuzzy score value (A), where the threshold value (d) for each item measured must be less than or equal to 0.2 (Cheng & Lin, 2002) the percentage of the experts' agreement must exceed or equal to 75% (Chu & Hwang, 2008), and the value of the fuzzy score value (A) must equal to 0.5 or above. For the ranking purposes, the highest fuzzy score value (A) is considered in the first position.

All eight elements tested met the conditions specified in the fuzzy Delphi method, namely, a threshold greater than 0.2 ($d \leq 0.2$), expert agreement greater than 75% with values ranging from 81% to 96% agreement, and a fuzzy score value greater than 0.5 ($A \geq 0.5$) with values ranging from 0.865 to 0.918. The analysis of the threshold value data obtained through the fuzzy Delphi instrument involving a total of 26 experts for construct of student learning and teacher effectiveness are shown in Table 3 and 4 below.

Table 3
Fuzzy Delphi analysis results on Students Learning

	Elements	***Threshold* Value (d)**	**% Expert Consensus**	***Fuzzy* Score *(A)***	**Expert Consensus**	**Rank**
S1	Leaders manage the school capacity to offer students a wider selection of STEM streams	0.133	88%	0.882	Accepted	5
S2	Leaders suggest implementation of STEM education in co-curricular activities (uniformed body activities, clubs and associations, sports and games) to provide more experience	0.096	96%	0.918	Accepted	2
S3	Leaders emphasize more hands-on activities through problem-based learning/project-based learning (PBL) approach	0.093	92%	0.919	Accepted	1

	to improve students' skills (communication skills, collaboration, critical thinking, creativity)					
S4	Leaders emphasize on creating excitement for students by exposing them to the diversity of STEM-based activities	0.106	88%	0.913	Accepted	3
S5	Leaders instill motivation among students by providing rewards for every effort shown	0.109	92%	0.900	Accepted	4

Table 3 illustrates the threshold values for school leaders' practices regarding student learning elements based on experts' consensus. The threshold value ranges from 0.093 to 0.133, envisioning the value is passed over the threshold value (d) of 0.2 (d > 0.2) as needed in the fuzzy Delphi method requirement. Element S3 – "*Leaders emphasize more hands-on activities through problem-based learning/project-based learning (PBL) approach to improve students' skills (communication skills, collaboration, critical thinking, creativity)*" threshold value (d) = 0.093 with the highest value of defuzzification = 0.919 exceeding fuzzy score value (A) ≥ 0.5 (de Hierro et al., 2021; Saedah Siraj et al., 2021) is ranked first. This is followed by the element S2 – "*Leaders suggest implementation of STEM education in co-curricular activities (uniformed body activities, clubs and associations, sports and games) to provide more experience*" threshold value (d) = 0.096 with defuzzification value = 0.918. Meanwhile, element S1 – "*Leaders manage the school capacity to offer students a wider selection of STEM streams*" threshold value (d) = 0.133 with defuzzification value = 0.882 ranked last based on experts' agreement. All five elements reach the percentage of experts' agreement range from 88% to 96% which exceeded 75%.

Table 4
Fuzzy Delphi analysis results on Teacher Effectiveness

	Elements	***Threshold* Value (d)**	**% Expert Consensus**	***Fuzzy* Score *(A)***	**Expert Consensus**	**Rank**
T1	Leaders promote innovation in teaching (such as integration of budgets and technological equipment, ICT, virtual platforms etc.)	0.107	88%	0.905	Accepted	1
T2	Leaders cultivate the implementation of action studies in a focused manner as a way of solving learning-related problems (e.g. Two selected action studies per year)	0.171	81%	0.862	Accepted	3
T3	Leaders encourage teachers to use modular approaches in teaching	0.152	81%	0.865	Accepted	2

Table 4 shows the threshold value for leaders' practices on teacher effectiveness. The threshold value (d) for element T1 – "*Leaders promote innovation in teaching (such as integration of budgets and technological equipment, ICT, virtual platforms, etc.)*" = 0.107 with defuzzification value = 0.905. This element ranked first among the three school leaders' practices. Element T3 – "*Leaders encourage teachers to use modular approaches in teaching*" threshold value (d) = 0.152 with defuzzification value = 0.865 ranked second. Meanwhile, element T2 - "*Leaders cultivate the implementation of action studies in a focused manner as a way of solving learning-related problems (e.g., Two selected action studies per year*)" threshold value (d) = 0.171 with defuzzification value = 0.862 ranked last based on experts' agreement. All the three elements reach the percentage of experts' agreement of more than 75% ranging from 81 % to 88%.

DISCUSSION

Throughout the consensus-building among 26 experts in this study, the practice related to leader's emphasis on hands-on activities through problem-based learning/project-based learning (PBL) in improving student skills was ranked as the most relevant practice for the school leaders in Malaysia regarding student learning. Such a finding is consistent with previous studies (Chen & Lin, 2019; Jackson et al., 2021; Murphy, 2022). Steger et al. (2020) also confirmed that hands-on activities proved to show significant statistics on student performance compared to simulation-based activities. Among the hands-on or activity-based learning approaches that are often debated can have a good impact on students is problem-based learning or project-based learning (PBL). PBL has become a relatively popular method to realize experiential, relevant and authentic learning (English, 2017; Wilson, 2021).

Moreover, the second most important strategy that leaders suggest to incorporate STEM education into co-curricular activities to provide students more exposure is likewise unquestionable. STEM co-curricular activities have been discovered to present supplementary opportunities for students, both academically and socially, through innovative activities beyond the realm of the syllabus. This aids in transforming them into self-assured learners and responsible citizens, in addition to excelling in their academic pursuits (Mtika, 2019). Some students develop a heightened interest and motivation towards STEM due to the implementation of co-curricular activities (Stringer et al., 2020). By participating in comprehensive co-curricular STEM activities, students are able to refine their creativity and enhance their ability to solve problems (Ozis et al., 2018).

Furthermore, both the leaders' behavior to create excitement for students in activities by exposing them to the diversity of STEM-based activities and the leaders' practice to instill motivation in students through rewards for each effort made are connected to meaningful learning. Students' motivation and involvement can be greatly increased in a setting that promotes a fun and engaging learning experience. Students learn meaningfully when they apply their knowledge and cognitive abilities to solve problems, enabling them to provide context to their experiences (Mayer, 2002).

The strategy of leaders organizing school capacity to offer a wider selection of STEM stream to students is considered as the least appealing practice for student learning among the school leaders' practices in strengthening STEM instructional programs. In Malaysia, 16-year-old students have the autonomy to select academic streams that align with their individual interests, inclinations and abilities (Kementerian Pendidikan Malaysia, 2021). Student autonomy was defined as the ability to take charge of one's own learning. It involves allowing students to take ownership and responsibility for their learning, enabling them to choose their approach to learning, the resources they use, and the pace at which they learn (Evans & Boucher, 2015).

Meanwhile, the most pertinent practice to support teacher effectiveness is the leader's ability to promote innovation in teaching on raising the quality of STEM learning. Innovation in teaching refers to the development and implementation of new and creative teaching methods to enhance the learning experience for students. Teachers' acceptance of technology has a positive effect on teaching innovation involving ICT and this situation is also linked to teachers' self-efficacy and leadership roles in organizations (Chou et al., 2019). There are many other approaches to teaching innovation that have been discussed in the literature i.e new pedagogic theory, methodological approach, teaching technique, instructional tool, and learning process (Serdyukov, 2017), so it is not just limited to the use of technology. However, it is acknowledged that the influence of technology in education benefits teaching because it has had a significant impact on the world of today.

The second strategy to enhance STEM instructions through teacher effectiveness is the leaders' encouragement for teachers to use modular approaches in teaching. The modular approach is a useful alternative that teachers can utilize to deliver teaching and learning because there are numerous syllabuses that must be delivered to students in a constrained amount of time. This approach has been found to be effective in previous studies (Ali et al., 2010; Ambayon, 2020), as it allows teachers to teach STEM topics in small, manageable units that build upon each other. This promotes students' deeper understanding of the concepts covered and provides the opportunity to learn at their own pace while allowing for differentiation and personalized learning.

Last but not least, the leaders' practice to cultivate the implementation of action studies to solve learning-related problems has turned out to be the least desirable component of teacher effectiveness. Despite being the least preferred approach, action research is a potent technique that concentrates on practical issues. Action research, which typically focuses on classroom, lab, or school concerns, is a research technique that teachers can utilize to enhance their teaching methods, assessment tools, and student learning outcomes. Teachers have the greatest ability to apply every knowledge and skill that can have the highest influence while conducting action research since they are the people closest to students who know and watch their progress (Glickman et al., 2018).

CONCLUSION

As education continues to evolve, school leaders play a critical role in ensuring the effectiveness and quality of STEM instruction within their schools. School leaders can produce exceptional learning outcomes by focusing on purposeful learning that fosters transferable knowledge and skills acquisition. In addition, promoting teacher effectiveness and facilitating student learning are crucial elements that school leaders should incorporate into their STEM instructional programs. By leveraging effective strategies for school leadership, teachers can create innovative and inclusive environments for STEM learning that inspires and motivates students. School leaders must continue seeking opportunities to improve and grow professionally while supporting their teachers to do the same. This approach enhances the school's capacity to deliver an unparalleled learning opportunity to all students, ensuring that they are ready to tackle the challenges of a rapidly evolving world. Undoubtedly, research on strengthening STEM instructional programs by school leaders is still limited. This study offers valuable insights into enhancing both student learning and teacher effectiveness. It also serves as a solid reference for future research and highlights the necessity of conducting a more detailed qualitative or quantitative study.

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