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Research Article:

Implementing and Facilitating STEAM Problem-Based Learning From the Perspective of Teacher Leadership

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ABSTRACT

Science, Technology, Engineering, Arts and Mathematics (STEAM) education taught through Project-Based Learning (STEAM PBL) has expanded across 22 states in the United States in the last two years. The literature on STEAM teaching is just emerging with most of the studies having focused on descriptions of newly established STEAM schools and how the teaching methods have been incorporated in classrooms. These studies have mainly used qualitative research or case study design. While the majority of the studies have described what is going on in terms of STEAM teaching, little is known about what type of school leadership can best facilitate the implementation of STEAM PBL. This study explores this gap by examining the source, process, practices, and effect of teacher leadership in relation to the implementation of STEAM PBL. Data from 18 interviews with teachers in eight middle schools in a southern low-performing district point to the importance of ongoing, hands-on professional development, effective professional learning teams of teachers, and teacher leadership for the effective implementation of STEAM PBL teaching.

Keywords: Problem-Based Learning (PBL), STEM, professional learning community, Teacher Leadership

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INTRODUCTION

Science, Technology, Engineering, Arts, and Mathematics education (STEAM) taught through Project-Based Learning (STEAM PBL) has expanded across 22 states in the United States in the last two years. The literature on STEAM teaching is just emerging; most studies have focused on descriptions of newly established STEAM schools (e.g., Erikson, 2013) and how the teaching methods have been incorporated in classrooms (e.g., Park & Ko, 2012). These studies mainly have used qualitative research or case study design (Douthit, 2021). While the majority of the studies have described what is going on during STEAM teaching, little is known about what type of school leadership can best facilitate the implementation of STEAM PBL. The implementation of any instructional change requires teachers' extra efforts or commitment, added responsibilities, new learning, professionalism, collective efficacy, collaboration, supportive, trustful and collegial relationships and innovation (Fullan, 2016). In our current era of rapid change, sustainable education change must be grounded in the continuous learning and development of teachers, especially through effective learning communities in schools (Lieberman & Pointer Mace, 2008; Louis, 2006; Parise & Spillane, 2010; Timperley, 2011; Tschannen-Moran, 2014). This is especially true for implementing STEAM PBL. This interdisciplinary teaching requires teachers to develop cross-subject, grade-wide, or even school-wide projects together, set common teaching and learning goals, develop common assessments, and coordinate and collaborate to a great extent. Thus, on one hand, teachers need to learn and implement this new approach as teachers; on the other hand, they have to develop common teaching and learning goals, help each other to learn and implement new curriculum, coordinate and collaborate, and monitor the program's success as leaders. Teachers' roles as teachers and leaders are intertwined and inseparable, embedded in collaborative school-based learning, professional learning communities, or collaborative inquiry (Bryk & Schneider, 2002; Hoy & Tschannen-Moran, 1999; Louis, 2006; Qian & Walker, 2013; Wang, 2016; Youngs & King, 2002). To ensure the success and sustainability of such processes, open communication, trustful relationships, commitment, extra efforts and professionalism are essential (Hallinger et al., 2014; Terzi et al., 2020; Tschannen-Moran, 2014; Zheng et al., 2019). All these are central to teacher leadership.

Some scholars (e.g., Wenner & Campbell, 2017) have defined teacher leadership in terms of teachers who take on leadership responsibilities outside the classroom. Other scholars, however, have adopted a broader conceptualisation of teacher leadership that includes leadership both within and beyond the classroom: identifying with and contributing to a community of teacher learners and leaders, influencing colleagues toward improved educational practice, and accepting responsibility for improving student learning outcomes (e.g., Katzenmeyer & Moller; Nguyen et al., 2019). The latter definition posits that teaching and leadership are integrated. This study adopts this latter approach and examines the source, process, practices and effect of such teacher leadership in relation to the implementation of STEAM PBL. Specifically, we asked the following questions:

1. How were teachers prepared with teacher leadership for STEAM PBL?
2. What was the process of professional learning communities (PLCs) in school that support STEM PBL?

3. What were the teacher leadership practices that facilitated the implementation of STEAM PBL in schools?
4. What were the effects of this leadership on teachers and student learning outcomes?

LITERATURE REVIEW

Science, Technology, Engineering and Mathematics (STEM) is focused on the importance of producing and maintaining a steady pipeline of workers with solid scientific and technological knowledge and skills (Honey et al., 2020). STEM education was designed to support occupations encompassing these areas of study in fields including government, military and industry. More importantly, this emphasis is directed toward ensuring that the nation's competitiveness in the global economic markets will improve. STEAM is a framework for teaching science, engineering and technology that develops STEM further through including arts, all based on mathematical elements (Yakman, 2011). While STEAM teaching can be implemented in several ways (e.g., Cook & Bush, 2018; Kim & Bolger, 2017), STEAM PBL has been spreading quickly in the last few years and is being implemented in schools in many states including Alabama, Florida, Ohio and Texas, and in international jurisdictions such as England, Australia, China and South Korea. Very little research, however, has been reported regarding the best school leadership for engaging the whole school system in implementing STEAM teaching (e.g., Petersen, 2022) in K-12 settings. For example, among the 20 studies, Douthit (2021) reviewed that examined major research findings related to STEAM curriculum implementation, only one (Ellis, 2018) examined the roles and responsibilities of principals regarding arts education and its influence on student academic achievement. This study fills in this gap. In the following sections, the literature on STEAM PBL teaching and teacher leadership is reviewed. Key dimensions of teacher leadership that constitute the tentative STEAM PBL teacher leadership framework that guided the study are identified.

STEAM PBL Teaching

STEM is a type of educational inquiry where learning is placed in context and students solve real-world problems through the creation of opportunities—a pursuit of innovation. STEAM does not merely add art to STEM; it changes STEM's focus from better test scores in the core STEM academic disciplines to a better quality of inclusive thinking and from a focus on the development of a larger technically competent workforce to one that is also more innovative (Watson & Watson, 2013). This results in a paradigm shift in teaching and learning. In the STEAM paradigm:

1. Art and engineering reinforce each other.
2. Art helps enhance the interplay of the left brain, dealing with logical thinking, and the right brain, dealing with perceptual thinking; this interplay supports creative and instinctive thinking.
3. Art disrupts the traditional structured, logical flow of the thinking processes in

STEM disciplines, and thus provokes innovative ideas (Redeen, 2013; Watson & Watson, 2013).

A limited but increasing body of literature (Liu et al., 2006; Lynch et al., 2005; Yazzie-Mintz, 2010) supports the effectiveness of this approach to teaching in terms of enhancing students' skills in a variety of ways.

Teaching STEAM subjects through PBL has gained popularity in the last 20 years. PBL involves students in design, problem-solving, decision-making, or investigative activities and gives students the opportunity to work relatively autonomously over extended periods of time, culminating in realistic products or presentations (Jones et al., 1997; Thomas et al., 1999). The underlying assumptions that support PBL are rooted in research on situated cognition and autonomy. PBL combines problem-based learning and project-based instruction. The past several years of research on PBL and its cognates suggests that PBL helps achieve interdisciplinary teaching, engages students' hearts and minds, provides real-world relevance for learning, helps students gain deeper content knowledge by applying what they know to new situations, increases students' confidence and skills in problem-solving, and helps students collaborate, communicate ideas, and be creative innovators (Dougherty & Conard, 2016; Holm, 2011). Emerging and limited evidence suggests PBL enhances students' motivation and learning interest and engagement and fosters student achievement gains, in particular by developing lower-level cognitive skills. Learning higher-level cognitive skills via PBL is associated with students' increased capability in applying these learnings in novel, problem-solving contexts (Hess et al., 2016). PBL is an effective method for teaching complex processes and procedures such as planning, communicating, problem-solving and decision-making (Grassick, 2016). Most of the research on PBL has focused on "planned" projects, problems, or curricula rather than on teacher-initiated projects or problems. PBL helps enhance a school's collaborative learning culture, teacher professionalism, and student attendance and self-reliance, and improves attitudes (Thomas, 2000). Despite these advantages, PBL teaching is also associated with limitations such as requiring a lot of time and expertise from teachers to design a rigorous PBL teaching plan and dealing with tight schedules and pressure for the final product presentation within regular school schedules, which affects the development of basic psychological needs, especially competence and autonomy (e.g., Boss & Larmer, 2018; Nicolas & Ramos, 2022).

Leadership Needed to Support and Facilitate STEAM PBL in Schools

While the literature has indicated the usefulness of STEAM PBL teaching for better engaging students and achieving better learning results and school culture, what is needed are guides or strategies on how to best to implement it in schools. While a majority of leading scholars in the field of leadership have made efforts to develop overarching or inclusive leadership models (e.g., Leithwood et al., 2010; Robinson et al., 2009; Waters et al., 2003), other scholars have tried to develop more specific leadership models to address

different contexts such as data-driven leadership and school leadership for charter schools. None of these leadership models have had adequate application in STEM schools as most of these models were developed based on schools without a STEAM or STEM focus. The implementation of STEAM PBL requires a whole-school approach, with totally different schedules and structures, a revolutionary teaching mentality, a new interdisciplinary teaching approach, and new instructional skills and forms of teacher collaboration. Hence, a school leadership model may exist whose features are more effective than other such models in promoting this revolutionary change in teaching practices and learning environments. Empirical evidence on this, however, is scarce. This study explores this gap.

STEAM PBL teaching needs many people working together in a collective, coordinated way. It is collaborative and interdisciplinary, and it requires teachers to plan together and organise themselves around collaborative projects at the grade or school level. Practicing this new form of teaching and learning successfully is likely to require a substantial commitment to change from existing, more individually centred pedagogies. STEAM PBL teaching relies on teacher teams working together; thus, some teachers must take leadership roles to achieve effective collaboration and implementation.

Ongoing preparation for STEAM teaching in the form of effective PLCs can be the most effective way for teachers to develop instructional capacity. Key features of effective PLCs are shared vision or goals, collective responsibility for students' learning, developing lessons jointly, shared decision-making, common assignment and assessment, mutual engagement, frequent communication, data-informed instruction, and shared repertoire (e.g., Bolam et al., 2005; Herro et al., 2017; Jho et al., 2016; Kim & Bolger, 2017; Stoll et al., 2006). PLCs foster student success best when teachers in different subjects or from different grades work together to analyse data, develop common assessment tools, identify difficult students, and share instructional practices that work (Herro & Quigley, 2016; Wynn & Harris, 2012). PLCs are powerful ways to foster teachers' learning from each other and improve teachers' collective instructional capacities in schools (DuFour & Fullan, 2013). Thus, PLCs provide the ideal venue for teachers to plan STEAM PBL together, design lessons across classes, grades, and the school, help each other grow professionally, share effective instructional strategies, model what works and provide feedback. PLCs can also boost teachers' efficacy in implementing new instructional programs (Valckx et al., 2020). All of these are central elements of teacher leadership.

School administrators should also be part of the leadership that supports STEAM PBL, learning with teachers, being there for them, visiting classrooms, talking with teachers, and sharing and celebrating positive things along the way. In other words, the leadership in STEAM schools should be distributed among the principal and all STEAM PBL teachers. Thus, the leadership effective for STEAM PBL (STEAM PBL leadership hereafter) also extends to the notion or domain of distributed leadership (Gronn, 2005; Spillane, 2003) in its coordinated, planful form (Leithwood et al., 2008) and to middle leadership (Day & Grice, 2019), a relatively recent phenomenon in the educational leadership literature that is close to teacher leadership. Premised on activity and distributed cognition theories, Spillane and his

associates (2003), were among the first scholars to introduce a distributed perspective as a frame for studying leadership practice. They focused on the productive and collegial interaction of all stakeholders and argued that the conceptualisation of distributed leadership is not just about the actions of individual leaders but rather about interactions among leaders, followers and the situation. Distributed leadership can be conceptualised as a collective, situated and distributed practice, not equivalent to a teacher's behaviour or a function of her/his knowledge and skill, but rather consisting of interactions between teachers and students related to intellectual material and aspects of the situation (Spillane, 2015). The distributed perspective on leadership has been examined in more depth in two lines of research: teachers' instructional leadership (e.g., Muijs & Harris, 2003), and more recently, middle leadership (Day & Grice, 2019).

Although instructional leadership was originally advocated for principals, recent research has extended to the examination of teachers exercising such leadership (Hallinger, 2005). It highlights the evolving role of teachers in school leadership and their potential impact on student outcomes. Instructional leadership can influence the quality of school outcomes through the alignment of school structures and classrooms by means of the school's culture, and through modelling rather than through direct supervision, or evaluation of teaching (Hallinger & Heck, 1996; Heck & Hallinger, 1999). Middle leading happens in the spaces between school-wide senior leaders and classroom teaching colleagues (Gregory Marshall, 2012). Middle leading has an indirect impact on the quality of classroom teaching and student outcomes (Day & Grice, 2019) and a direct impact on the professional learning of fellow teachers (Edwards-Groves et al., 2018). The amount of authority and influence middle leaders have in a school varies (Day & Grice, 2019; Grice, 2019; Youngs, 2014). Leading from the middle does not mean that this leadership is in a middle tier. Instead, it means getting close to the teaching and learning that is at the heart of the profession (Hargreaves & Shirley, 2020).

Although teacher leadership, middle leadership, instructional leadership and distributed leadership overlap, this study chose to approach the research topic from the perspective of teacher leadership because teachers are the main actors or agents of change who will be implementing STEAM PBL in the classroom and across schools. When STEAM PBL is implemented, teachers' practices extend from teaching within their classrooms to leading other teachers and managing STEAM projects across classes and across subjects, within and beyond their traditional spheres of influence. Teachers' collective efficacy in and commitment to teaching STEAM PBL, and professionalism while doing so, are enhanced through their collaborative inquiry, professional learning teams, and development and implementation of STEAM PBL lessons together. All these are central dimensions of teacher leadership. I will review the relevant literature on teacher leadership in relation to STEAM PBL teaching and identify dimensions that are most essential to STEAM PBL teaching. These essential elements constitute the theoretical framework of STEAM PBL teacher leadership for this study.

TEACHER LEADERSHIP FOR STEAM PBL TEACHING

Newer conceptions of teacher leadership tend to expand the notion from formal leadership roles to include leadership practiced through more informal means (Nguyen et al., 2019). The practice of teacher leadership is advocated because it fosters employee participation; expertise in teaching and learning; acknowledgment, opportunities, and rewards for accomplished teachers; and benefits to students (Wenner & Campbell, 2017). Research on teacher leadership in the past 40 years has examined four central aspects of this leadership: (1) source of leadership (e.g., instructional knowledge and pedagogical excellence); (2) influence process (e.g., through establishing collaboration); (3) the most common teacher leadership practices or dimensions or method of influence identified through meta-analysis or systematic reviews (e.g., Shen et al., 2020); and (4) effect or outcomesof influence on individual teachers, school effectiveness and student outcomes (Nguyen et al., 2019).

Source of Teacher Leadership

Sources of teacher leadership influence can be grouped into two broad categories: human capital and social capital. The former includes a teacher leader's expertise and experience (e.g., Allen, 2016; Avidov-Ungar & Shamir-Inbal, 2017; Hatch et al., 2005), whereas the latter places an emphasis on the teacher leader's professional relationships with peers including social networks (e.g., Fairman & Mackenzie, 2015; Firestone & Martinez, 2007; Fullan, 2010; Hargreaves & Shirley, 2020; Smylie & Hart, 1999).

Influence Process

Teacher leadership involves a process of change, rather than a role or formal position of authority, where teachers are the key change agents and sources of innovation (e.g., Anderson, 2004; Smith et al., 2017; Snoek et al., 2017). It is demonstrated through sharing instructional practices, initiating changes, peer collaboration and contribution (e.g., meetings of PLCs), and informal interactions (e.g., daily exchanges, sharing, and communication with other teachers) based on mutual benefit, respect and trust (e.g., Allen, 2016; Baecher, 2012; Baker-Doyle, 2017; Chew & Andrews, 2010; Nolan & Palazzolo, 2011; Smeets & Ponte, 2009; Yost et al., 2009).

Method of Influence

Teacher leaders primarily influence their peers through developing trusting relationships, supporting their colleagues, and engaging in professional collaboration, contribution and interaction (Collinson, 2012; Fairman & Mackenzie, 2015; Huang, 2016; Nicholson et al., 2017; York-Barr & Duke, 2004; Yow & Lotter, 2016). Teachers enact and exercise their leadership role through sharing innovative ideas and resources, modelling new practices, encouraging colleagues and developing trustful relationships (Nguyen et al., 2019).

Effects

Teacher leadership influences at least three levels: the individual, school and student levels (Nguyen et al., 2019; York-Barr & Duke, 2004).

Individual level

The strongest effects of teacher leadership have been on teacher leaders themselves (York-Barr & Duke, 2004). By engaging in leadership activities, teacher leaders benefit from growth in their leadership knowledge and skills (e.g., Avidov-Ungar & Shamir-Inbal, 2017; Wenner & Campbell, 2017; White, 2014), and thus demonstrate positive changes in their instructional practices (e.g., Margolis & Deuel, 2009; Yager et al., 2013).

School level

Teacher leadership can result in improvements in peer relationships; teachers' collective instructional capacity; curriculum reforms; teacher self-efficacy, collective efficacy, and commitment to school; and PLCs (e.g., Angelle & Teague, 2014; Beachum & Dentith, 2004; Friedman, 2011; Fullan, 2016; Hairon et al. 2015; Hofstein et al., 2004; Lai & Cheung, 2015; Liu, 2021; Sebastian et al., 2017; Silins & Mulford, 2004).

Student level (direct and indirect effects)

Teacher leadership has a significant, direct effect on student learning, academic growth, and student engagement (Sebastian et al., 2016, 2017; Shen et al., 2020). It also has an indirect effect on these student outcomes through the mediation of teachers' own and others' classroom instruction (the latter through teacher–peer influence), and through shaping the school learning climate (Supovitz et al., 2010; Yost et al., 2009).

This framework, outlining the major dimensions of the teacher leadership, guided our study. The research questions were asked in relation to each of the four aspects of teacher leadership outlined above (i.e., source of leadership, influence process, teacher leadership practices and effect, or outcomes). In the next section, I will describe the method used in the study.

RESEARCH METHOD

STEAM teaching is a relatively new idea that lacks a clear guide for implementation (Peters-Burton et al., 2019). Therefore, the best approach to describing and exploring this new teaching approach is to conduct a qualitative research study (Merriam, 2009). A qualitative researcher is interested in understanding how people interpret their experiences, how they construct their realms, and what sense they make out of their experiences

(Merriam, 2009). The criterion of purposeful sampling (Creswell, 2014) was used to select the school district where this study took place. This district was chosen for the study because it had implemented STEAM PBL teaching in all eight of its middle schools. The district was in a traditionally underserved area in a central, southern U.S. state. Improving student achievement has become one of the state's priorities since 2018. Some schools were in cities, and others were on the outskirts of cities. In 60% of the schools, 50% or more students received a free or reduced-cost lunch. In a few schools, the majority of the students were African Americans. Two to four lead teachers from each school who had piloted STEAM teaching methods and were recommended by their principals were interviewed. In total, 18 teachers from the eight schools were interviewed and provided valid data for this study. Interviews were one hour long. We developed the interview protocols with semi-structured, open-ended questions. The interview protocols covered the following topics:

1. The source of STEAM PBL teaching knowledge and skills (i.e., professional development (PD) training and support).
2. Professional learning teams (PLCs) focused on STEAM teaching.
3. The influence of STEAM teaching on teachers and student learning outcomes.

The 20 interview questions were structured around the corresponding four research questions. Representative questions in each of these three areas in the teacher interviews were as follows:

1. Do you think the STEAM training was helpful for gaining STEAM PBL teaching knowledge and skills? In what way? (These questions probed district-led PD sessions and two-day workshops)
2. How was the process of the PLC focused on STEAM PBL teaching started in your school? Was it effective? In what way? Or why?
3. What did you or others do that was helpful in facilitating the implementation of STEAM PBL?
4. In what ways has your involvement in STEAM PBL training and PLCs influenced your instructional capacity?
5. In what ways has the STEAM PBL teaching you implemented influenced student learning? Can you give an example?

FINDINGS

This study discovered that both district-led professional development and STEAM training activities aided teachers' understanding of STEAM teaching. Teachers learned about the attributes of STEAM teaching best in collaborative teams when adequate common planning time was available with opportunities to observe others' STEAM teaching in classrooms, and when clear instruction or guidance was communicated on the scope of STEAM projects. Resources, time, structures for STEAM lesson planning, effective professional learning teams, and a clear vision of expectations for teachers regarding the goals, processes, and results of STEAM teaching and the specificities of lesson plans

were essential to the success of the implementation of STEAM PBL. STEAM teaching definitely helped better engage students, fostered their higher order thinking and problem-solving skills, and improved their knowledge retention. We elaborate on these findings in more detail below. They are organised around the four research questions.

Q1: How Were Teachers Prepared with Teacher Leadership for STEAM PBL?

All sixth-grade teachers in the eight middle schools were trained for STEAM teaching in the summer of 2014. The district designed an exemplar of STEAM teaching. Also, district-wide training sessions were provided for teachers monthly. Teachers met twice (once in October and again in November) as a group to exchange ideas on their feelings and learning from the sessions. The directors in the Curriculum and Instruction units in the central office visited schools to provide support. Basic supplies for STEAM teaching were provided, which included computers for students and laptops for teachers who implemented STEAM teaching. Almost all teachers commented that the central-office-led teacher PD sessions were very helpful and played a large role in helping teachers to develop STEAM teaching capacities. During the sessions, teachers met together, collaborated and brainstormed on how to implement STEAM lessons. They shared ideas and instructional strategies that could be applied to other subjects. As well, the act of district leaders' visiting schools and answering teachers' questions was reported as being very helpful. The district provided funding for substitute teachers, which teachers felt was helpful. Teachers met colleagues from other schools and in their cluster schools, which also was beneficial for them and helped them to understand what others were doing. The most valuable experience for teachers was talking with teachers from an exemplar STEAM-certified school, which helped them to get to know what STEAM teaching looked like.

Despite the training and central-office-led STEAM sessions, the majority of the teachers interviewed expressed they did not know what STEAM teaching really looked like (e.g., teaching in action with students) and were unsure where to start. When participating in PD meetings, they had expected more examples of what STEAM teaching would look like in the classroom. There were no reference materials to refer to for answers. Teachers created "ideas" but needed examples of other educators applying the methods of STEAM for comparison. This would allow for self-evaluation and the chance to improve. One teacher reported, "I don't think we really understood exactly what was expected of us. I wanted to see a written agenda, like what everybody did throughout it. We don't know how to carry out the Tornado Patricia lesson plan. At the end of the semester, we figured that each school would have a different plan." Another teacher commented: "At the end, we've all concluded that the project didn't go from one school to the other." Yet another teacher commented, "Don't convince me why, just show how."

Based on these statements, it can be assumed that the philosophy of STEAM was well-received by teachers but how to implement it was unclear. After training and PD sessions, the teachers did not have a clear vision of STEAM teaching and how it related to other initiatives in the district. For example, some teachers thought STEAM was introduced to

challenge students' and teachers' thinking. Others thought it was an extension of the state STEM initiative with just more intensity. A few teachers mentioned STEAM as being an extension of social studies. Certain teachers expressed that it was a totally new way of teaching, and thus they needed to change their mindset or beliefs. Lastly, there were conflicting beliefs among teachers about the target student population for STEAM PBL teaching: Some thought STEAM was for academically inclined students, while others viewed the program as available for all students, including those at risk or with disabilities. In some schools, STEAM core teachers generally did not know how to incorporate the arts into the sciences. In others, teachers felt STEAM training was too focused on science and, therefore, struggled to integrate subjects like social studies into the projects. This confusion about the purpose of STEAM had teachers struggling, and as a result there were inconsistencies in implementation.

Finally, these data show that more professional development was needed to help teachers to maintain momentum once the implementation started. The lingering issue of how to go about furthering their skill levels remained. As one teacher commented,

> If humans were to live on Mars, we would have them build a settlement on Mars, but it would be a lot of stuff doing that, and I have never really gone that far because there are so much science to make it real, and not pretend, but they would have to do a lot of research to do it, and so I think that the kids would enjoy doing something like that, but I wish I had more of a direction.

Q2: What Was the Process of PLCs in School?

There were four types of STEAM PLC in the eight schools. Three schools started to build effective PLCs that were well planned and coordinated. In these schools, principals set common planning time and structure/grade teams to work on STEAM. As one teacher commented, "It is a learning process and it is exciting. We have a really good team here that works together well. All want to be better." Not only was the mandated STEAM PBL topic "Tornado" was discussed, but other topics were also brainstormed and planned, such as a space trip between America and Russia, a wax museum, and the stock market. Two features are essential for a school STEAM team to function: common planning time to share ideas and principals' attending the STEAM training sessions so that the strategies and instructional processes teachers are expected to perform will also be grasped by administrators.

The second type of PLC consisted of spontaneous collaboration between teachers to design and carry out STEAM teaching, which took place in a few schools during the STEAM PBL implementation process. Such spontaneous collaboration happened in the hallways during breaks, and after school. This is when teachers talked about STEAM teaching implementation, shared ideas, and helped each other solve problems. Teachers did not report discussing any other STEAM teaching topic than the initially mandated one on "Tornado."

The third type of PLC existed in a few schools where spontaneous collaborative structures loosely existed. It was found that principals there typically would set aside an hour in the morning twice a week for planning and professional development. Teachers deemed this as inadequate and wanted more prep time to learn the concepts of STEAM. Finally, there were schools that already had an existing PLC with teachers practicing collaboration well before the introduction of STEAM. In such cases, teachers used the existing structure to help each other and share ideas and activities.

Regardless of the type of PLCs at the schools, all teachers expressed that the greatest benefit of PLCs was the communication of ideas on how to teach the content and the sharing of resources. Teachers also mentioned that talking with teachers in other subject areas helped to inform them of what others were doing. One teacher mentioned that they had a group text going to communicate. Another remarked,

> I guess I would have to go back to ideas, resources, just being able to share the ideas, like when we sat down at the table, at the beginning of school, to plan out our STEAM lesson, the math teacher was pulling out ideas, the science teacher was pulling out English ideas, and they were taking them from each other, using those ideas. Before STEAM, we had never sat down and said 'Okay, this is our STEAM team, and what ways can we help each other?'

The first type of PLC, which was well planned and coordinated, as well as supported and attended by the principal, served as the best means through which teachers developed STEAM PBL knowledge and skills. It was also through this means that teachers' leadership was best nurtured and exercised.

Q3: What Were the Teacher Leadership Practices that Facilitated the Implementation of STEAM PBL in Schools?

Some of the teacher leadership practices were reported to be very helpful to facilitating STEAM PBL teaching. These induded teachers':

1. Getting together to collaborate as a grade and to organise their ideas for that specific STEAM PBL topic through frequent team meetings.
2. Being supportive and offering encouragement and support to each other.
3. Watching others' teaching and classes and giving comments.
4. Working with the instructional coach, sharing ideas, making sure the other teachers were on the right track and showing what it is supposed to look like.
5. Working with teachers from other schools during the half-day panning sessions the district provided.
6. Having common planning time each day to ask questions and meet. All teachers taught the same students every day.
7. Changing the school learning culture.
8. Involving parents and community.

For example, in one school, teachers figured out how to begin the STEAM lesson plans during the 15-minute planning session each morning. They decided that the science teacher would start with the subject first, introducing Tornado Patricia, and then it would trickle down to the English teacher, enabling them to get started all together.

About parent involvement, one teacher reported STEAM helped teachers and parents work together and shared ideas. Example:

> We had a parent and his friend coming in and operated the Ham radio for us. They had a whole PowerPoint. We have also had Officer Weaver, and he actually had the footage of the Tornado, on a, like a sky-cam from the police department, and he showed the kids how fast the Tornado Patricia goes from one big cloud to it actually forms a Tornado Patricia, and how smaller Tornado Patricia came off of that. I had never seen it, and my kids were in awe.…They absolutely loved it.

Teachers observed that students were used to coming in and doing the same thing that they had always done, but now they came in and did hands-on activities every now and then, thinking about similar topics in all their other classes, and "it really sparked their interest because there is so much." Parents also emailed teachers about what they were supposed to do to help kids to build the houses. Teachers were excited about it; the community was excited about it.

By teachers' working together, taking knowledge from other teachers and modelling for students, students could think and learn across disciplines. Implementing STEAM could encourage students to think about what they could do in the future in their careers. It changed the culture of the classroom from pencil and paper.

Q4: What Was the Effect of Teacher Leadership on Teachers and Student Learning Outcomes?

Direct effects of teacher leadership on teachers

Enhancing Human Capital (STEAM PBL Instructional Knowledge and Skills). After the implementation of the Tornado Patricia lesson plan, teachers felt more comfortable in planning, provided more hands-on instruction and science experiments, and used more technology. As one teacher remarked, "I think that we are all willing to talk and try new things, so I think that's good." Overall, teachers learned to focus more on problem-based and project-based teaching.

STEAM PBL also enabled teachers to think outside the box. As one teacher described:

> STEAM does heavily focus on science, technology, and engineering. I have been challenged to try to figure out how to bring that into my teaching. I am trying to start with the technology part. I understand that technology is more than just turning on a computer and having the kids to search for something on Google. I am trying to incorporate more of that in my lessons, and I am also working with the other teachers to make sure that, even though we have our own course of study, that we figure out a way to make them combine so that the students will hear some of the same vocabulary in each classroom. They are using the same skills in each classroom. I am thinking outside of my social studies box.

STEAM training, PLCs and implementation changed teachers' mindsets in the following ways:

1. Since the programme was student-oriented, teachers assisted their students to do research.
2. Teachers learned to see students as problem solvers, rather than receivers of knowledge.
3. Teachers realised how working in groups is important for students, especially when grouped according to their personalities.
4. Teachers learned to generate students-oriented activities.
5. It gave teachers the chance to develop content and work to address student weaknesses.

Enhancing Social Capital. Teaching interdisciplinarily really took shape in one school. It aided teachers in looking at the many disciplines of STEAM as a composition, rather than as individual components. As a teacher commented:

> Our first project focused on Tornado Patricia. What I did, I used the information about the Tornado Patricia as the background information for the project to teach primary and secondary sources to the students. In turn, the students used the data that they saw as a secondary source and applied it in their Math and English classes. It was the start of teaching students how to use technology to help them with primary and secondary sources. Using STEAM lessons, I, along with the other teachers, were able to teach skills and content to students as well as show how one topic can be cross-referenced among courses. STEAM teaching facilitated teachers' work with each other and, at the same time, schools joined together to construct new ideas for instruction. For new teachers, STEAM teaching offered settings (inside their own schools and other schools) to develop professional relationships with experienced teachers.

STEAM provided an opportunity for teachers to plan together and tie up several Common Core standards together in one project. The majority of teachers felt STEAM promoted

rigor in teaching, which correlated well with the state's Math, Science, and Technology initiative. It was eye-opening for teachers to see how students developed social skills and problem-solving skills while doing hands-on activities, and what students needed to resolve problems, such as, critical thinking and linking learning with careers or jobs. Teachers mentioned, "We have never been that intense before."

Indirect effects of teacher leadership on student learning

Enhancing Students' Engagement. STEAM teaching enhanced students' engagement with and enjoyment of learning. One teacher commented:

> The students were very engaged because the project was relevant to them. They asked many questions and wanted to spend more time doing it. I think because it is more personal to them since it was in their hometown, and many of the students went through the Tornado Patricia.

Furthermore, STEAM PBL teaching helped teachers to reach more students. As one teacher mentioned, "STEAM teaching has given me a faster way of reaching students. I feel like I can reach out to a bigger group of learners that I may have not reached out to." Another teacher expressed a similar sentiment.

Relating Learning with Real Life. STEAM PBL teaching allowed students to relate what was learned in the classroom with real-life situations. For instance, a typical hands-on learning lesson was to demonstrate how Tornado Patricia was formed. Teachers built wind-resistant houses that even included small furniture. With an anemometer, the teacher measured the wind speed until the houses started to tear apart. The activity consisted of much trial-and-error. Since the teachers and students used scotch tape, duct tape, hot glue, and nails, – the structures stayed together. A huge fan was used, but the anemometer could not reach 25 mph. This led to the use of a gas blower and a leaf blower, but to no avail; the well-built structures held up. They did manage to destroy a house made of Lego, as consolation. Students really enjoyed the activity and were able to relate it to their real homes during the discussion following the experiment. Because the learning had become more meaningful for students, they displayed a greater takeaway of the lesson. In fact, following the Tornado Patricia unit, students were motivated to bringing in pictures of the tornado to class. A teacher shared the following story as demonstration of the continuous effect of the unit:

> One little girl, for example, her cousin was the WVUA meteorologist. He sent pictures and a video from himself, talking about the weather. One little girl was actually in the tornado, and she brought before and after pictures of her house, and you could not see the school that was half a mile away from her house, but after the Tornado Patricia you could actually see it.

Shifting the Ownership of Learning Back to Students. STEAM teaching started to shift the ownership of learning from teachers to students and increased students' critical thinking. It aroused students' intrinsic interests in nature and made them think about what they wanted to do when they grew up. As one teacher commented:

> All the teachers are trying to help the students in their final student-led project. It makes the responsibility of learning the priority of students; it causes the students to increase their critical thinking skills. As student-oriented activities were generated and implemented in many classes, students were actively involved in their own education.

Enhancing Students' Problem-Solving Skills. STEAM teaching enhanced students' skills across subjects, which included searching for primary and secondary sources, graphing, reading charts, presenting data, and searching for information. Students worked in groups and presented information, tweeted, interviewed, and made charts, graphs, and brochures. For example, during the Tornado Patricia lesson, the kids did a picture of the siren that was located at their house. They used Google first and then drew latitude and longitude like a graph. Students brainstormed and helped to make a house strong to resist big wind. Students were very elaborate and decorated them. In all, STEAM enhanced the students' problem-solving skills.

Improving Knowledge Retention. STEAM teaching stimulated students' thinking and alleviated knowledge retention. Students in one school were learning all the way across subjects. After the implementation of the Tornado Patricia unit, one girl said, "This is a disaster. All the teachers want to talk about is Tornado Patricia here." Another teacher commented:

> …kids were actually so involved, usually they do not get a say in their learning, but this time they were so involved in their own education that they were actually, for the first time all year, excited. We have finished STEAM weeks ago. The kids even made a short story using weather words.
>
> ….Like, you can tell that is embedded in their minds, not like memorising something then forgetting it.…When they got to see the glitter floating around and making a Tornado Patricia, their faces were lit up.

One teacher in one school actually did a before and after survey of the kids. She asked three questions, basically, "How do you feel about STEAM? How do you think it is going to help your learning/Do you think it is going to help your learning? Do you think cross-curriculum topics will help you learn more?" They actually said no and explained why before STEAM teaching, but afterward they started saying yes and stated that they had learned a lot more from STEAM and doing the cross-curriculum.

DISCUSSION AND CONCLUSION

The findings of this study show both district-led PD and school PLCs enhanced the source of teacher leadership for STEAM PBL. When it provides purposes, real teaching examples, hands-on training and clear operational instruction, district-led PD can enhance teachers' knowledge and competency in STEAM PBL teaching (i.e., their human capital). The well-planned, principal-attended PLCs not only enhanced teachers' own capital but also social capital. Such PLCs provided effective means for teachers to influence each other. This was achieved, especially, through teachers' collaborating across disciplines, supporting each other, developing lessons together, setting teaching and learning goals, experimenting with this new approach to teaching, thinking outside the box, sharing and collaboratively constructing knowledge in STEAM PBL teaching and instructional strategies, and sparking community interest and thus enlisting community support. Such teacher leadership practices enhanced teachers' collective instructional capacities in schools and their collective efficacy in and commitment to STEAM PBL teaching. These practices made the school culture more supportive, collaborative and enabling, and indirectly enhanced students' engagement and enjoyment of learning. They built on STEAM's great potential to increase students' multiple skills including higher order thinking, critical thinking, interdisciplinary inquiry and problem-solving skills. That said, this study also identified some urgent needs that must be addressed for STEAM PBL to be better implemented and supported by teacher leadership.

First, teachers need to be better trained to enhance the source of their leadership. STEAM PD needs to be more hands-on. However, teachers in this study may have been too reliant on getting STEAM right rather than experimenting with it and taking advantage of the opportunities given. STEAM PBL teaching is new. There is no guide for it and no cookie-cutter approach that can be used to implement it. Empowering and motivating teachers to experiment with it and spreading best practices may be the most effective ways to implement it at this beginning stage. As Hargreaves and Fullan (2013) argued, best practices, defined as existing practices that already have a good degree of widely agreed effectiveness, need to be identified and bilaterally shared. This study found that, to implement STEAM teaching involving the whole staff in a school, there needs to be a collective inquiry into best practices and the school's current reality, as well as continuous commitment to examining evidence or results and an emphasis on using them to fuel continuous improvement. This is like any successful change as continuous improvement and collective inquiry into best practices are needed to achieve cultural change (DuFour & Fullan, 2013; Organisation for Economic Cooperation and Development [OECD], 2012). It is only through such a process of continuous reflection and improvement that "next practices," the innovative approaches that often begin with teachers themselves and will sometimes turn out to be the best practices of the future (Hargreaves & Fullan, 2013), can be developed. This is essential to the initial stage of implementation of STEAM teaching as we found through this study, or to any changes.

Second, this study suggests that treating STEAM PBL professional learning and implementation as a process involving all teachers' informal leadership is key. This is

consistent with what DuFour and Fullan (2013) argued, that change is not a program. The temptation to find a quick fix due to the growing sense of urgency about the need for education reform will not do (Fullan et al., 2006). An action orientation or "learning by doing" and a commitment to continuous improvement in implementation is the key to sustaining change (DuFour & Fullan, 2013; Leithwood et al., 2010), and this applies to the sustainability of STEAM teaching. School and district leaders, as well as teachers, need to learn about and implement well-planned, effective STEAM PBL PLCs. PLCs carefully established and nurtured by principals can encourage teachers to work together, learn from each other, and help each other (e.g., Buttram & Farley-Ripple, 2016; Hallinger et al., 2019). Teachers improved their schools' collaborative culture and instructional capacity through such PLCs and during the implementation of STEAM teaching. A high level of instructional capacity developed through effective teachers' professional learning is probably the most prominent feature in high-performing school systems (Jensen et al., 2016; OECD, 2012). PLCs, when implemented well, provide the most effective context for improving teachers' three types of capital (i.e., human, social and decisional). Decisional capital is the ability to make instructional decisions based on research evidence and student data. In this study, teachers in PLCs learned how to focus more on problem-based and project-based teaching. Teachers also learned how to design working groups to foster success. Teachers' human capital increased through this new learning. Teachers felt the greatest benefit of professional learning teams was communicating, sharing ideas about how to teach content and sharing resources. Teachers learned best from working with colleagues and from observing other teachers in a STEAM-certified school. It is through such collaborative inquiry and sharing processes that teachers' collective capacities are enhanced, which is key to all successful changes (Fullan, 2011, 2013; OECD, 2012; Stoll et al., 2006). Teachers developed trustful relationships with each other through working together, and these positive relationships reinforced their trust in experimentation and collaboration further in the couple of schools where professional teams were well developed. Moreover, these events enhanced teachers' social capital in schools. Teachers also discussed how students benefited from STEAM pilot teaching and how they could improve STEAM lesson units. Hence, their decisional capital was improved. A well-implemented and carefully supported process, guided by principals, has great potential to improve teachers' professional capital in schools (Hite & Milbourne, 2022). To achieve these positive results, pitfalls such as a lack of resources, support, and time for and hands-on training in PLCs should be avoided as should vague expectations for the PLCs and collaboration, and STEAM PBL implementation.

Third, this study suggests the following practices should be enhanced:

1. Fostering teacher commitment to evidence or results and their use for fueling continuous improvement (sustaining the change process).
2. Developing principals and teachers' understanding of, collective efficacy in, and leadership skills in facilitating STEAM teaching.
3. Developing teachers' understanding of, collective efficacy in, and instructional skills in developing STEAM lesson plans and implementing STEAM teaching.

Teachers' commitment to STEAM teaching comes from what works, students' enjoyment, and teachers' ability to reach out, plan and implement. Commitment will come when teachers have more understanding and experience of STEAM teaching. Thus, the key aspects of teacher training and implementation as identified in the recommendations above must be addressed in order to enhance and sustain teachers' commitment to STEAM teaching. It is teachers' intrinsic desire to see students succeed that encouraged teachers in this study to try STEAM teaching, be open to ideas, and be willing to step out to try new things. This intrinsic desire should be rewarded with administrative support, common planning time and resources. System-wide support and quality training and PD should be in place to ease teachers' concerns. School administrators should be learning with teachers, be there for them, visit classrooms, talk with teachers, and share and celebrate the positive things along the way. The literature has shown that the extent to which teacher commitment can be influenced depends on the extent to which the value syntax of the teacher is aligned with that of the principal (Sun, 2004). Trusting relationships must be nurtured or enhanced to sustain the momentum for student success (Tschannen-Moran & Gareis, 2015). This is true in the implementation of STEAM teaching as well, as found in our study. Trusting relationships are especially essential to teacher leadership when teachers embark on learning the new methods of STEAM teaching (Piyaman et al., 2017). Teachers' collective efficacy also needs to be enhanced before teachers can be willing to try new things (Leithwood & Louis, 2012).

Finally, more mindful and skillful support from principals is needed to foster teacher leadership for STEAM PBL. Teachers insisted that they needed more meetings, research that tied into standards and resources. Additionally, more collaboration between teachers to have students connect different subjects was needed. Resources are essential. There was a lack of Wi-Fi, smart boards and computers for students (though teachers had them) that hindered the implementation of STEAM teaching. In the schools where principals almost had no knowledge about this type of teaching and no knowledge about how to facilitate it, teachers demonstrated spontaneous leadership, which turned out to be not very helpful in terms of facilitating and implementing STEAM PBL. In contrast, the schools with more positive outcomes were the ones that upheld the norms of teamwork and openness. The principals and teacher leaders worked closely together and communicated regularly with the schools' faculty. Frequent and ongoing opportunities should be provided for faculty to share feedback and to participate in shaping the role of the teacher leader (York-Barr & Duke, 2004).

This study adds to our understanding of what teacher leadership looks like in the context of implementing STEAM PBL teaching. The findings confirm the importance of the essential dimensions and practices of teacher leadership identified in previous reviews or research (Nguyen et al., 2019; Schott et al., 2020; Wang & Xia, 2022; Wenner, & Campbell, 2017). More studies are needed to identify representative teacher leadership practices and their antecedents. Knowledge in this regard can inform the development of teacher leadership (Ding & Thien, 2022). A few limitations of the study are associated with its small sample (only eight schools), tentative claims due to the qualitative methodological

approach and restriction to only middle schools. Future research conducted with large-scale data, quantitative research methods and schools at the other levels can reveal more insights into teacher leadership and how it facilitates STEAM PBL teaching.

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