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Supporting transdisciplinary STEAM practices: Integrating architectural modelling into mathematics education through a cross-cultural dynamic lesson plan (DLP) tool

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Abstract

This paper proposes a cross-cultural dynamic lesson plan (DLP) tool that could be adopted by teachers across different cultures to implement STEAM (Science, Technology, Engineering, Arts & Mathematics) education practices. An abundance of well-developed lesson plans is available to teachers on numerous Internet sites, but the cultural diversity of such lesson plans – i.e., difficulty to customize for alignment with local curriculum and lesson plan requirements, make it difficult for teachers to utilize and share these resources – due to the lack of flexible customizations for orientation with local curriculum and lesson plan requirements. This study suggests an approach to overcome such challenges by presenting the DLP tool to assist teachers' STEAM teaching practices using GeoGebra for learning content elaboration. Our proposed transdisciplinary STEAM practice uses architecture as a real-life example that connects mathematics learning to culture and history through mathematical modelling. This study follows a design-based research approach to develop and implement DLP tool and its related design heuristic. Moreover, the study is examining how the DLP tool can be utilized with teachers cross-culturally and how it could support teachers in professional development workshops to design transdisciplinary STEAM lesson plans. The qualitative analysis of teachers' artefacts developed during these workshops demonstrated the versatility of DLP tool to address cultural diversity in lesson planning through these STEAM practices applications. The emerging themes from this study show that regardless of participants' cultures, using the DLP tool to implement transdisciplinary STEAM practices could support teachers in developing operational and shareable lesson plans.

Keywords: Architecture, Culture, Lesson planning, Mathematics, STEAM education

Introduction

Lesson planning is a fundamental factor in the teaching and learning process in educational constitutions (Orziqulova & Absamadova, 2020). Milkova (2012) defines the lesson plan as, "the instructor's road map of what students need to learn and how it will be done effectively during class time" (p. 1). Lesson planning procedures are diverse across cultures and educational contexts. Although there is an abundance of lesson plan resources created by teachers around the world, cultural differences do not often support convenient transfers among these different settings (Aydin, 2014). In addition, the lesson planning tasks are often time-consuming, especially for novice teachers (Srikoom, 2021). Furthermore, it is even more challenging to plan lessons that include transdisciplinary approaches such as STEAM (Science, Technology, Engineering, Arts & Mathematics) practices (Hurley, 2001). Likewise, STEAM lesson preparation is considered a complex and challenging practice for teachers (Srikoom, 2021), especially when applied in conventional ways. Therefore, this study proposed a new interactive tool to assist teachers in constructing STEAM lesson plans.

Some teachers document their lesson planning process by using technology tools such as Microsoft Word, Microsoft Teams, Google Docs, or PowerPoint (Huang et al., 2021) while others use a traditional paper and pen approach. Some teachers plan lessons collaboratively, while others prefer to do this task individually. Nevertheless, the lesson planning stage is proved to be crucial for teaching and learning in educational constitutions (Orziqulova & Absamadova, 2020). In some cultures and traditions, teachers follow a defined template or scheme offered by schools or authorities (Causton-Theoharis et al., 2008). According to Winsløw et al. (2018) the current practices of lesson planning are limited by cultural boundaries, are not universal, and cannot be easily transferred between different settings. He also suggests that this situation is caused by the tradition of lesson planning being an individual task for teachers' personal uses. To address this challenge that lesson plans are not shared between teachers, this study followed the design-based research (DBR) approach to develop and evaluate a design heuristic that acts as a layout for teachers to assist them in designing STEAM-based lessons.

We utilize GeoGebra software (https://www.geogebra.org/) in this research as it is the most widely used software for mathematics education around the world; it is free of charge and possesses some features for the development of transdisciplinary STEAM education.

The developed design heuristic includes a dynamic lesson planning (DLP) tool (El Bedewy et al., 2021), GeoGebra book, GeoGebra Classroom and professional development (PD) workshop materials. The proposed DLP tool could support teachers' implementation of STEAM practices for learning mathematics in diverse cultural and educational settings through the use of architectural modelling. Moreover, technology supports modelling and visualization of architectural models. As designed, the DLP differs from conventional lesson planning tools because of its dynamic nature. Meaning it is an interactive web-based tool allowing teachers to alter lesson components. Furthermore, lesson components preferences are reflected in real time during the planning process. In addition, the DLP tool is integrated facilitating incorporation between several disciplines and scalable to include several more disciplines according to the teachers' preferences for their lesson plans. Therefore, the DLP tool could become a cross-cultural tool enabling teachers to plan their lessons if they choose to implement transdisciplinary STEAM practices. Our STEAM-based framework promotes the knowledge of interdisciplinary and transdisciplinary connections and technological awareness necessary to implement STEAM practices and activities in teaching and learning (Lee & Lee, 2014).

In our proposed STEAM practices, we use architectural constructions as culturally relevant real-life examples for teaching-learning situations that may contribute to mathematical learning through applying architectural mathematical modelling. Moreover, the purpose of using architecture is to develop transdisciplinary connections to culture and history. Therefore, these STEAM practices are transdisciplinary in nature (Caton, 2021; Costantino, 2018) as they connect various STEAM disciplines and establish connections among STEAM subjects, to architecture, culture, and history. Applying such transdisciplinary practices could enable teachers to connect disciplines and organize teaching and learning by overcoming conventional boundaries drawn between disciplines and could assist the construction of meanings and understanding through real-world problems (UNESCO International Bureau of Education, 2013). Transdisciplinary STEAM is composed of five main disciplines, and we added architectural, cultural and historical connections to further bridge disciplines' silos in STEAM education (Caton, 2021). Transdisciplinary also promotes explorative approaches by allowing the adaptation of several creative methodologies and methods within disciplines to advance solving complex real-world problems (Durall et al., 2022). Transdisciplinary learning characteristics necessitate a union of adaptability, reflexivity, active involvement, dialogical exchange, flexibility, and collaborative endeavors among all educators involved in the formulation of transdisciplinary lesson plans (Klein, 2018).

In sum, the purpose of this study was to develop a DLP tool to support teachers' implementation of STEAM practices for learning mathematics in diverse cultural and educational settings through the use of architectural modelling with technology. We will explain the research rationale linked to the selected theoretical frameworks and outline how we developed DLP tool components and how teachers used the DLP tool cross-culturally in our design-based research study.

Literature review

This section will examine and analyze different arguments that may support the idea of introducing lesson planning tools for using transdisciplinary STEAM practices in the literature. Special focus will be placed on issues of integrating technology and the role of creativity in the lesson planning process.

STEAM lesson planning tools

Lesson planning is not an easy task for teachers because it highly demands their time and attention. Moreover, from one teacher to another lesson planning tasks could vary across cultural and educational contexts. In addition, lesson planning depends on a variety of teacher factors such as teaching experiences, educational background, and discipline foci.

Lesson plans focusing on one discipline are usually different from lesson plans that require technology integration and/or integration of two or more disciplines which makes transdisciplinary lesson planning more complex for teachers. Hurley (2001) classified such integration into four main approaches: 1) Disciplinary integration; 2) Multidisciplinary integration; 3) Interdisciplinary integration; and 4) Transdisciplinary integration. Integrating STEAM practices into mathematics education could take any of these approaches. STEAM education could be considered a transdisciplinary approach based on the dynamic integration of precise discipline frameworks (Soublis, 2017). Moreover, STEAM and transdisciplinary approaches share their aim in addressing real-world challenging problems or situations (Rodier et al., 2021). Furthermore, transdisciplinary creativity, problem-solving and method adaptation approaches are mutual to STEAM educational merits, which encourage teachers to promote them in their teaching (Guyotte et al., 2014). Therefore, teachers need to promote transdisciplinary STEAM practices that should be possibly considered in their lesson planning. Hence, Bush and Cook (2019) distinguish transdisciplinary as "going beyond the disciplines to create new knowledge or ideas". Furthermore, they recommend linking transdisciplinary student learning in more meaningful contexts with real world problems and situations.

Transdisciplinary STEAM practices can be difficult for some teachers to support in terms of educational means that include lesson planning and still satisfy the needs of the curriculum (Caton, 2021). Some educators use STEAM or pose problems to foster inquiry on a certain problem without a deep understanding of such inquiries and where they will lead in terms of connection to other disciplines. Moreover, educators should be aware of how the inquiry is presented to students that makes it crucial for how they understand it and are able to solve it.

According to Shernoff et al. (2017), this phenomenon may be attributable to the fact that a substantial number of educators did not receive pedagogical training in integrated

STEAM or transdisciplinary approaches within the context of STEAM subjects during their education. Therefore, Caton (2021) states that research is needed to clarify the transition between specifying or choosing an inquiry and implementing it. Furthermore, Caton (2021) and Quigley and Herro (2016) highlighted several barriers to implementing transdisciplinary STEAM educational practices such as teachers' understanding of STEAM, lack of time and school or institutional support. Hence, STEAM lesson content is needed for teachers to overcome these barriers (Caton, 2021). Therefore, we aim to provide a lesson plan as part of the research design heuristic for teachers to support their STEAM lesson planning and later implementation of STEAM practices that is needed to overcome the difficulties teachers face.

Teachers are prone to uncertainty while designing STEAM lesson plans, due to their lack of experience with STEAM and how they can apply STEAM lesson plans effectively (Kim & Bolger, 2017). Moreover, some other studies show that lesson preparation featuring the integration of STEM/STEAM practices into teaching is a complex and difficult process for teachers that requires a lot of support (Srikoom, 2021). Kim and Bolger (2017) conducted a study in a science methods course that examined Korean pre-service elementary teachers' experiences with designing STEAM lesson plans. Results of the study indicated that the experience of developing STEAM lesson plans had a positive effect on pre-service teachers' attitudes toward STEAM and enriched their own learning both in terms of interdisciplinary thinking and creativity in lesson planning. Kim and Bolger (2017) reported that as it was useful for pre-service teachers to get involved in interdisciplinary lesson planning activity it was challenging because of the uncertainty of how they can integrate disciplines and to what extent. Although most of the pre-service teachers believed that discipline integration is challenging, yet it could expand their students' future high-level thinking skills (Kim & Bolger, 2017). Furthermore, another study by Srikoom (2021) analyzed lesson plans developed by science teachers as part of a PD workshop that focused on STEM integration using the STEAM lesson rubric. This analysis revealed five main categories or themes for the lesson plans with different foci: "problem-based/project-based lesson, science and math incorporated with engineering design lesson, engineering design-based lesson, build-and-test-only lesson, and science activity lesson" (p. 5). The study demonstrated the variations in STEM lesson plans and identified that teachers found the preparation of STEM lessons time demanding. Teachers also struggled with the integration of STEM practices due to their lack of knowledge outside of their own disciplines. Hence, Srikoom urges researchers to develop frameworks to support the development of "STEM-focused educational materials (such as lesson plans, and media) to be a good supportive resource for teachers" (p. 7) and to provide guidelines to teachers for integrating STEM practices during the implementation of the ready-made lesson plans. Srikoom (2021) advised that future research is needed to provide "a suitable STEM lesson guideline that teachers can learn how to select those ready-to-use lesson plans that correlate with their goals (students' outcome)." (p. 7) to overcome these STEAM lesson planning obstacles. Therefore, in this study, we try to overcome these challenges teachers meet while designing transdisciplinary STEAM lesson plans through the proposal of our lesson planning tool.

Teachers who implemented lesson plans focusing on the same STEAM curricula were different because of their different perceptions of STEAM although they come from common cultural backgrounds. These different STEAM lesson plan outcomes could lead to different learning outcomes for students. As it was evident from Wang et al. (2011), who carried out a case study in the United States with three schoolteachers from the science, mathematics, and engineering disciplines. The purpose of this study was to see the teachers' attitudes and beliefs about STEM integration into their teaching and the connections between these beliefs and classroom practices. Based on the analysis of lesson plans developed by the participants, the study concluded that "teachers in different STEM disciplines have different perceptions about STEM integration and that leads to different classroom practices" (Wang et al., 2011, p1). In their results, they referred to the lesson planning by three teachers that were given the same task, but the lesson plans were rather diverse. Out of these findings, we advise that teachers should be trained to implement STEAM practices and later they should be guided on how to apply it and plan for it in their lessons. Hence, in this paper, we present our approach to solving STEAM lesson planning challenges, especially those that could result in different learning outcomes by providing teachers with a heuristic lesson planning tool.

Thus, this study focuses on addressing the needs identified by previous studies by developing a DLP tool for teachers to support the integration of STEAM practices during their PD workshops. Moreover, this study extends this task by making the DLP tool a cross-cultural tool that can be used by teachers across different cultural and educational contexts.

Creativity in lesson planning

Creative lesson plans can enhance the overall curriculum development and student learning and motivation (Baharun & Adhimiy, 2018). In order to introduce a tool for lesson planning that could promote creativity, we examined the role of creativity in existing lesson-planning procedures. Márquez et al. (2016) stated that in order to enable teachers' creativity they should be able to take risks and try new things in their classrooms. Simplico (2000) emphasized that there is a delusion about "easy" creativity, but rather it requires hard work, extensive planning, and research. Cicek (2013) suggests that one of the measures that define an effective teacher is his/her ability to develop multiple variations of a lesson plan and another modified lesson plan for students who need that. Therefore, in this study, the DLP tool was designed with the aim to support teachers in developing creative lesson plans for STEAM teaching practices.

Lesson plans should not be in the form of strict templates to be filled by teachers because this makes it difficult for teachers to be creative, rather it should be an interactive process of planning. John (2006) proposed an alternative dialogical model to focus on the process of lesson planning as a practice not only as preparation for teaching. In this model, in order for teachers to understand how STEAM practices are perceived by students, by planning their lessons teachers can predict how students will experience these lessons. This student-like simulation could act as a reflective tool for teachers allowing them to monitor how lesson content meaning is being preserved during the planning process. Further, John (2006) proposed that lesson planning should be approached in a more interactive way to give room for creativity, problem-solving and smart planning. Moreover, John also suggested that forcing teachers to follow or fill certain strict templates for lesson planning is concerning, but often encourages teachers to deviate from such strict blueprints to more interactive approaches for lesson planning that would also foster pedagogical intelligence. Therefore, this study focused on developing a lesson planning tool that offers teachers various options and ways to integrate their proposed STEAM teaching practices into their lessons.

Our aim behind developing the DLP tool concept is to engage teachers in designing tasks that suit their pedagogical goals and their students' needs. Furthermore, our proposed DLP tool aims to engage teachers to become more creative during their lesson planning processes and consecutively be more diverse in their teaching strategies later on.

Technology adoption in lesson plans

The lesson planning tool we are proposing is a web interface that prompts teachers to select instructional technology for the implementation of their proposed practices. Therefore, we will explore some examples from the literature that capitalize on technology integration in lesson-planning processes. Technology integration in these STEAM practices requires teachers to utilize various technologies to model and visualize architectural buildings they wish to create. Thus, technology serves as a platform for lesson planning procedures and as a technology selection opportunity for modelling and visualizing learning contents.

Teachers who were taught in traditional ways and not using technological tools may face difficulties in integrating technologies into their teaching (Stein et al., 2020). Stein et al. (2020) assume that this limitation could be overcome by introducing PD and programs to help in encapsulating technology in educational settings. These findings motivated us to implement such programs that may aid teachers to adopt technology and introduce them to new learning practices. Therefore, when we propose STEAM practices, we offer teachers a PD and scaffold them to learn the essence of technology, in our case GeoGebra modelling, visualization, and to implement transdisciplinary practices as we will highlight in the methodology section.

Digital, interactive and dynamic lesson plans could be important to facilitate today's teaching practices, especially those that incorporate a variety of technologies. Strickroth (2019) proposed an interesting platform that was developed to facilitate and digitize the lesson planning process, step out of the handwritten notes as traditional lesson plan techniques and assist in capturing teachers' intentions. Strickroth (2019) developed the software PLATON to stimulate teachers' self-reflection during the planning process by raising questions or providing advice that could support teachers' deeper understanding of planned lessons. PLATON includes supportive representation, various views, and analysis functions. Moreover, PLATON offers actual automatic feedback. Results of testing PLATON showed usability for lesson planning to teachers which helped them to manage their time and allowed them to self-reflect during the planning process. Therefore, Strickroth suggests that future work in the direction of the quality of lesson plans should be followed. Hence, in this research, we developed a web interface as a lesson planning tool that guides the teachers until they complete their lesson plans.

The idea of the DLP tool was inspired by the proposed research directions identified in the literature review which highlighted the importance of lesson planning. When we relate the above-mentioned findings to our proposed STEAM practices, this suggests that when teachers integrate STEM or STEAM approaches into their practices it might not be universal and could have different foci. Therefore, an implemented concept of the DLP tool is proposed to assist teachers in choosing the main components of their selected modelling tasks and assist them when applying them in their teaching. Moreover, our proposed DLP tool could aid teachers in developing creative lesson plans to enhance their students' learning experiences. Based on the studies above, technology integration may lead to advancing the quality of lesson planning and its applicability in classrooms. Therefore, the aim of this study was to develop a web-based DLP tool that could offer teachers a range of appropriate instructional technology tools, pedagogical practices and cultural awareness to utilize architectural modelling tasks in their classes. In the next section, we will discuss the theoretical foundations and the development of the study.

Theoretical framework

Besides lessons learned from the literature, the development of the DLP tool was based on a variety of theoretical considerations that we will highlight in this section.

Theories supporting DLP tool development

As our goal was to develop a DLP tool that could be used by teachers in the lesson-planning process across different cultures, we decided to adopt two frameworks. A lesson planning framework proposed by Milkova (2012) was adopted to develop the structure of the DLP tool to fit the needs of all teachers cross-culturally, while the Adaptive, Meaningful, Organic, Environmental-based architecture for Online course design (AMOEBA) framework (Gunawardena et al., 2003) informed the content of STEAM practices to take into consideration cultural variations.

Milkova (2012) proposed a simple framework for a lesson plan with three core components as follows: "1) Objectives for student learning, 2) Teaching/learning activities, and 3) Strategies to check student understanding" (p. 1). This framework suggests three critical questions that teachers need to consider when they plan their lessons. The first question, "What do I want students to know or learn from these practices?", defines the goals of implementing the STEAM teaching practices in mathematics and therefore directs teachers to select appropriate architectures to be used to achieve these learning goals. The second question, "What teaching and learning activities will I use?", defines the design of the tool leading to the selection of the other four main components of the DLP tool. These components address the learning activity, tools, and technologies to be used in the lesson, and the DLP tool also provides the learning environment options based on teachers' selection. The third question, checking for students' understanding could be achieved by several assessment methods. However, the assessment component was left out of the DLP tool enabling teachers with more flexibility when selecting their own assessment strategies. Nevertheless, based on future studies we aim to offer a variety of assessment strategies for teachers.

The AMOEBA framework (Gunawardena et al., 2003) provided a basis for the development of the content of STEAM practices to meet cultural variations. This included the learning and teaching materials, tools, methods, technology and learning environments. Hence, AMOEBA guided the design of our PD workshops for teachers. For example, the design considerations we included to meet cultural differences among participants were language differences, architectural examples shared with teachers, choices of technologies, and learning environments.

Design rationale for DLP Tool

The DLP tool combines the principles of the proposed STEAM practices for their implementation and future adoption. The DLP tool was designed to provide teachers with a sense of ownership, freedom of choice, and to embrace cultural variations and needs by providing various possibilities for the implementation of these transdisciplinary STEAM practices. Another purpose of including a variety of options in the DLP tool was to motivate and stimulate teachers' curiosity to explore available technologies and use them in various learning environments (Demir, 2011). Moreover, teachers are recommended to experience these practices and opportunities for implementation with the aid of the DLP tool, before introducing them to their students. Therefore, we offered PD workshops to the teachers where they had an opportunity to learn these STEAM practices. The next section will describe the methodology of the development of the DLP tool.

Methodology

This study followed a design-based research (DBR) approach (Figure 1). The DBR features helped in structuring our study in each phase and enhancing its outcomes from the iterations that took place cross-culturally.

The DLP tool was developed as part of the study's design heuristics. The study design heuristics served as a guide for teachers to understand and implement STEAM practices. Hence, the study design heuristics include the DLP tool, GeoGebra book, GeoGebra Classroom and the PD teaching materials, including architectural modelling examples customized to meet the cultural variations of the participants in each design cycle. In this paper, we focus only on the DLP tool as part of the study's design heuristic as a cross-cultural lesson planning tool.

In the first phase of the DBR cycle, the analysis, we expanded the idea of the proposed STEAM practices by collecting all the options we proposed for these STEAM practices implementations, in a simple tested and designed form of a lesson planning tool. Moreover, we analyzed the proposed options' applicability from a theoretical point of view including various architectural model types, learning environments and technologies. Afterwards, the proposed options were piloted and adjusted according to the piloting findings to understand the tool's applicability and to meet cross-cultural needs from architectural, environmental, and technological aspects. According to Bakker (2018), "Working as a researcher with a teacher (or teachers) generates a new layer of conjecture about what the teacher(s) might do or learn" (p. 59). Hence, during the analysis phase, we aimed to provide teachers with a lesson planning tool to aid them in implementing these STEAM practices.

In the DBR second phase, the development phase, we developed the DLP tool to support teachers in implementing STEAM practices and to help them in defining the components of their lesson planning. While the DLP tool is part of the study design heuristics, it is also

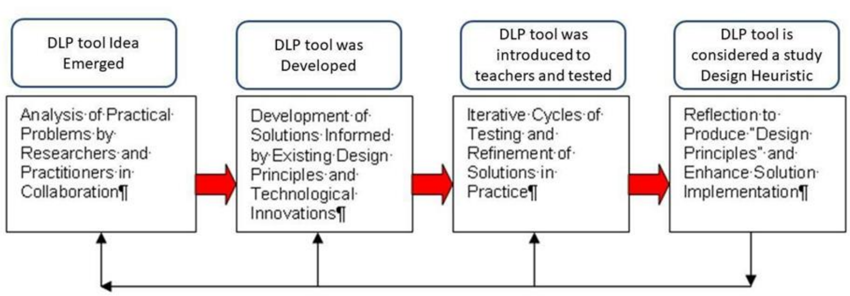

Fig. 1 The development of the DLP tool over the DBR phases, inspired by Reeves (2006)

supposed to be sufficiently broad in order to become a cross-cultural tool. Therefore, the DLP tool design was inspired by the idea of displaying the content in several layers that all affect and complete each other (Bakker, 2018). We defined layers by deciding what options are necessary to include in the DLP tool design following the theoretical framework recommendations. The main motivation in defining the components and layers was to offer teachers numerous options with which they can encapsulate in their STEAM practices as advised by Demir (2011) and to overcome any technology literacy or affordance issues that may hinder teachers from utilizing these STEAM practices. We will discuss the DLP tool components and design features thoroughly in the coming section.

The DBR approach has an interventionist nature (Bakker, 2018), therefore adopting this approach led to the necessity to investigate the DLP tool during the DBR iterative cycles. In the DBR model, in each iteration, the study design heuristic gets updated to an improved version based on the reflections and important insights we collected from teacher participants. Hence, after each iterative cycle of introducing the DLP tool to teachers cross-culturally during the PD workshops, we collected and analyzed data to improve the DLP tool by incorporating outcomes of each cycle into the next one. Hence, in the DBR fourth and last phase, based on the empirical findings that we collected through the research study iterations we updated the DLP tool development into an enhanced version to consider the DLP tool as a study design heuristic to support teachers in lesson planning of these STEAM practices cross-culturally.

DLP tool design heuristic

As described earlier, our DLP tool is a web interface developed to aid teachers in defining the lesson components to implement the proposed transdisciplinary STEAM practices that integrate architecture, culture, and history into mathematics. This tool offers teachers new ways and practices to engage students in mathematical learning in non-traditional and innovative ways. The DLP tool specifies architectural selection as one of its components, thus creating opportunities for the cultural and historical connections that are bound to the architectural models. These STEAM practices aim to foster mathematics learning through the mathematical modelling of architectural constructions.

The DLP tool was designed on the Unity platform which is a game engine for interactive and real-time responsive applications. Our tool is designed as a web portal accessible to teachers online to facilitate its usage by teachers across different countries. The main technology used for mathematical modelling is GeoGebra (https://www.geogebra.org/) because it is an open-source multi-language application that provides real-time monitoring of students' progress in the GeoGebra classroom; it has a developed feature that allows 3D printing and provides the augmented reality (AR) capability in a simple and straightforward way. GeoGebra is a dynamic platform that allows the dynamic visualization of various multiple representations and provides real-time feedback (Olsson & Granberg, 2019). The DLP tool consists of graphical representational elements such as buttons and text fields that allow teachers to choose what they like to add to their lesson plans (Figure 2).

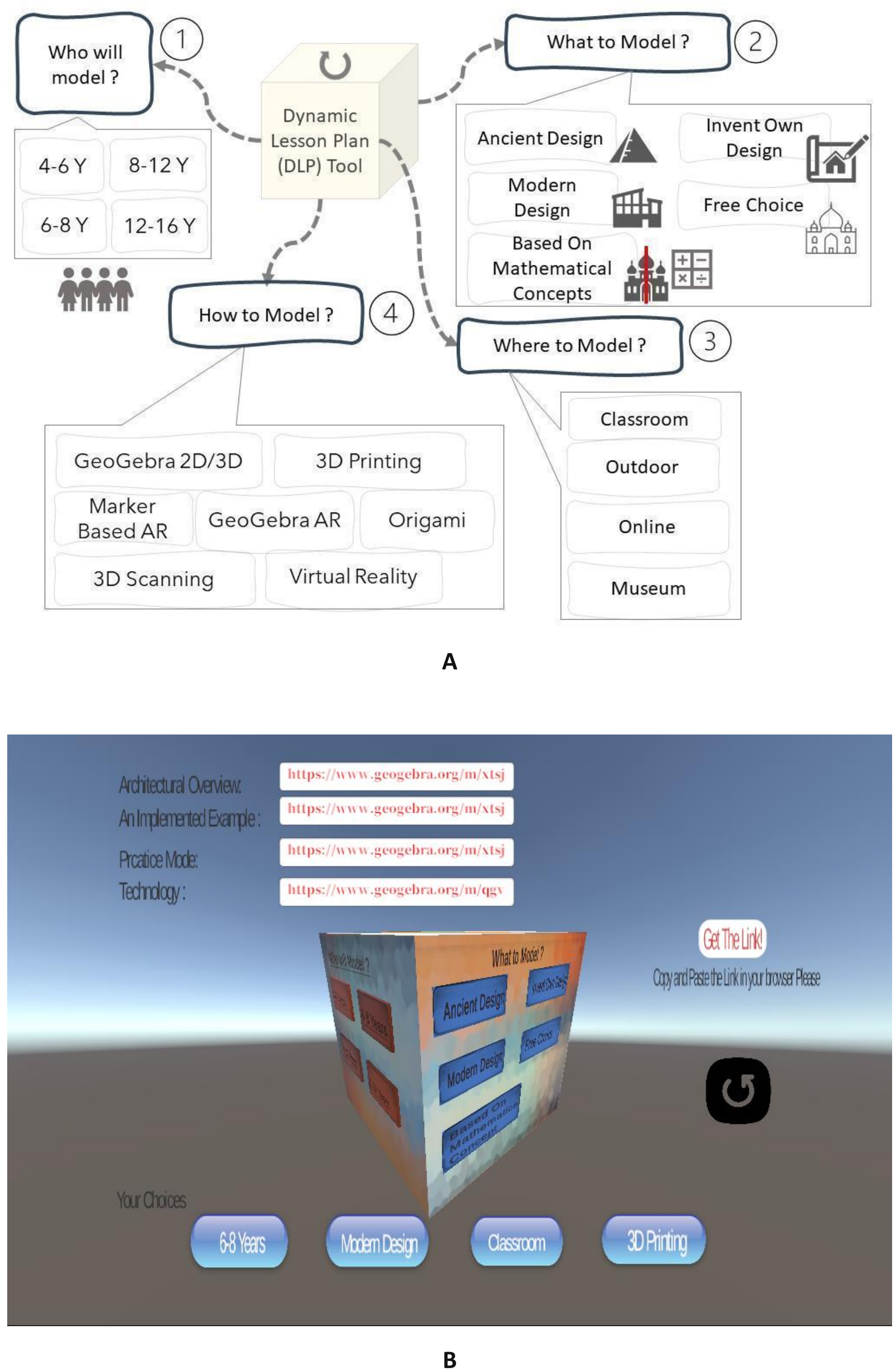

Fig. 2 A: The DLP tool components first version; B: The DLP tool web interface

Based on theoretical framework considerations from Milkova (2012) and the AMEOBA framework (Gunawardena e al., 2003), the DLP tool was designed to include four components that the teacher has to specify in the lesson planning process. Each component has several categories (Figure 2). The first component of the DLP is the students' age group which was divided into several age groups for teachers to adjust the complexity of the architectural modelling tasks according to the students' age groups. The second component is the architecture appropriate for the mathematics learning goals of the lesson. Hence, teachers can specify the type of architecture they would like to include in their lessons as ancient, modern, based on a mathematical focused area, design their own architecture or a free choice. The architectural choices the teachers choose are connected to the cultural and historical emphasis they want to create in their lesson plans. The third component is the learning environment where the teacher intends to implement STEAM practices with the students. The proposed learning environments for implementation of these STEAM practices with teachers range from formal learning environments (classroom/online) to non-formal learning environments (museums/outdoor). Finally, the fourth component is the technologies that would be used to visualize and model mathematically selected architecture. We created several technological options to support technology literacy or affordance for teachers (Demir, 2011). Moreover, we categorized the technologies into physical or digital technologies to foster the 3D transformation idea of representing the same architectural model in digital and physical form. Hence, the digital technologies options available are GeoGebra, AR and 3D scanning, while the physical technologies options available are 3D printing, 4D frames and Origami.

After teachers choose the DLP tool's four components they can press a user interface (UI) button that allows them to navigate to specific chapters in the developed GeoGebra book to match their preferences. The GeoGebra book chapters were designed following the DLP tool's structure and its aim is to provide teachers with detailed heuristic instruction and implemented examples on how to use the DLP tool components to match their preferences. As an illustration, consider the following scenario: A teacher specifies an ancient architecture as her modelling preference for the second DLP tool component. The DLP tool then displays a specific link to the GeoGebra book chapter, providing the teacher with examples of ancient architecture modelled using GeoGebra. These examples include mathematical modelling using polygons, transformations, and extrusions. Furthermore, the GeoGebra book provides teachers with theoretical and cultural background about architectural examples. Next, if the teacher chooses museum learning environments as the third component of the DLP tool, then she is directed to the GeoGebra book chapter with examples about these learning environments and how to employ them. Furthermore, if teachers choose GeoGebra AR as their technological choice, then the specific GeoGebra book chapter provides a user guide on how to use and apply GeoGebra AR along with implemented examples.

Introduction of the DLP tool to teachers

During our PD sessions, teachers first learned about STEAM practices and then teachers had an opportunity to explore the DLP tool and its components on their own without any guidance. We utilized this step to observe the teachers' intuitive explorations that helped us to determine possible enhancements to the DLP tool necessary for the interface usability and cross-cultural adaptation that we will describe later in this paper. After teachers' explorations, we explained the components of the DLP tool and the sequence that the teachers should follow in order to complete the lesson-planning process. Teachers defined the DLP tool lesson components for their own learning of these STEAM practices during their PD. DLP tool technologies and learning environment options allowed us to show teachers several possibilities on how they can encapsulate the proposed transdisciplinary STEAM practices in their teaching.

Research questions

The study explored the implementation of the DLP tool with teachers during PD and examined the use of the DLP tool by teachers across cultures. Therefore, this study is guided by the theoretical frameworks to investigate the following research questions.

RQ1: What are the factors of the DLP tool that enable lesson planning for teachers cross-culturally in diverse contexts?

RQ2: How does the developed DLP tool support teachers in experiencing transdisciplinary STEAM practices during their PD workshops and for planning future lessons?

Methods

This section is describing the study's selected participants, how the DLP tool was introduced to them, followed by a description of the instruments and data analysis – with the aim of showing the various views that teachers have on the DLP tool, especially those coming from diverse cultural backgrounds.

Participants

The study used a homogeneous purposeful sampling approach to select participants based on research questions to include preservice or in-service mathematics teachers. The participants were recruited using personal communication with the instructors of PD courses teaching STEAM or GeoGebra education from different geographic regions to assure the cultural diversity of participants. In the end, we worked with 20 in-service and 5 pre-service teachers from diverse geographic locations (Figure 3).

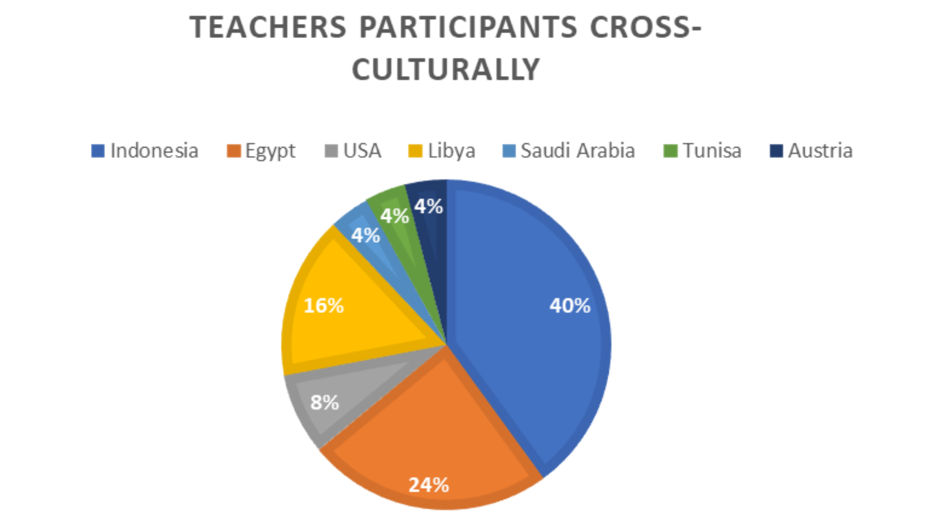

Fig. 3 Geographic distribution of study participants

The demographics of the study participants are shown in Table 1. We used pseudonyms to conceal their identity and later we will refer to their practices by name in the results section.

Table 1 Teachers' demographic data

Pseudonym	Country	Status	Age	Age of taught students
Maria	Austria	In Service	33	15-16
Sophia	USA	In Service	35	13-14
Mark	USA	In Service		14-18
Nadia	Libya	In Service	42	10-13
Mona	Libya	In Service	51	13-15
Lara	Libya	In Service	50	9-15
Zaynab	Libya	In Service	31	11-15
Karim	Saudi Arabia	In Service	34	17-19
Raafat	Tunisia	In Service	45	15-19
Ahmed	Egypt	In Service	35	15-17
Sarah	Egypt	In Service	26	9-17
Laura	Egypt	In Service	22	7-10
Reem	Egypt	In Service	23	7-13
Yara	Egypt	In Service	23	7-13
Yunus	Egypt	In Service	50	6-15
Selim	Indonesia	In Service	26	10-15
Zaynab	Indonesia	In Service	38	22
Remal	Indonesia	In Service	26	16-17
Layan	Indonesia	In Service	23	12-13
Youmna	Indonesia	In Service	24	12-18
Shaza	Indonesia	Pre-Service	26	NA
Rayan	Indonesia	Pre-Service	27	NA
Dora	Indonesia	Pre-Service	23	NA
Ulla	Indonesia	Pre-Service	23	NA
Bella	Indonesia	Pre-Service	22	NA

Instruments

Semi-structured interviews were conducted with participating teachers after introducing the DLP tool to them. The interview protocol consisted of four parts, the first three parts concentrate on general information asking about teachers' educational backgrounds, their teaching approaches, their practices in developing their lesson plans, their uses of technology, their familiarity with GeoGebra, their prior knowledge of STEAM education and their perceived views on STEAM education. The fourth part of the protocol focused on the DLP tool design. It consisted of five questions to evaluate teachers' opinions about the DLP tool after it was introduced to them. For example, we asked whether or not it was easy to use and understand if they would try the different components of the DLP tool in their future teaching if they would use it in the future with their students how/why, and finally if they could provide any recommendations for enhancing the DLP tool from their own point of views.

Later we distributed a questionnaire to collect data on participants' reflections after introducing the DLP tool. The questionnaire included five open-ended questions focused on the DLP tool, teachers' choices, their opinions, suggestions and recommendations for the tool. We also asked questions about the GeoGebra classroom to evaluate the DLP tool during their PD. Moreover, we also observed teachers during the PDs by taking field notes and video recorded some PD sessions as well as we collected the artefacts, GeoGebra constructions and word/pdf documents describing the cultural and historical backgrounds of the selected architectures they developed during the sessions.

Data analysis

We followed a qualitative approach to analyze the collected data. Teachers' artefacts were analyzed using relational document content analysis. The video of participants' responses to the semi-structured interviews were transcribed and then translated into English. Responses to the questionnaire, text responses, were translated to English and combined with interviews which were analyzed using inductive-deductive coding. We classified the codes into generic codes that were added to the codebook prior to the analysis as they were deductively determined from the theoretical frameworks. Followed by codes that were inductively created from the analysis of the collected data, and later added to the same codebook. We applied data triangulation by conducting the same analysis process across data sources to identify emerging themes in order to develop a comprehensive understanding of the DLP tool usage and views by participating teachers.

Results

The analysis of data resulted in several sets of themes that were divided into sub-sections. Firstly, those themes addressed the DLP features for diverse contexts application that includes the participating teachers' feedback on the DLP tool, teachers' views on students' use of the DLP tool, their recommendations on how to enhance the DLP tool and their interest in using the DLP tool in their teaching practices. Accordingly, the second set of emerging themes from the data analysis was divided into cultural and non-cultural themes. The last set of themes of this section provided an analysis of how the teachers used the DLP tool during PD.

Features of the DLP tool for diverse contexts utilization

This section presents results of the analysis of the DLP tool features that enabled this tool to be used by teachers cross-culturally and in various contexts. This addresses the first research question.

The first emerging theme is participating teachers showed a positive attitude towards the DLP tool in terms of its structure, usage and usefulness for their STEAM practices lesson planning. In response to the question of whether the participants would use the DLP tool as part of their lesson planning process, 24 teachers answered "yes", and one teacher answered "not sure". Teachers reflected on their understanding of the DLP tool in terms of its aims and functions, and how it could help them in implementing these STEAM practices. To better illustrate emerging themes, we added quotes of participants reflecting their opinions on the DLP tool and STEAM practices. We placed these quotes on the map to better identify teachers' views related to their geographical locations.

Teachers in different geographic locations described the DLP tool's main features as "well organized, easy to use, helpful and straightforward" as evidenced from the interviews of the teachers from USA, Egypt and Saudi Arabia (Figure 4).

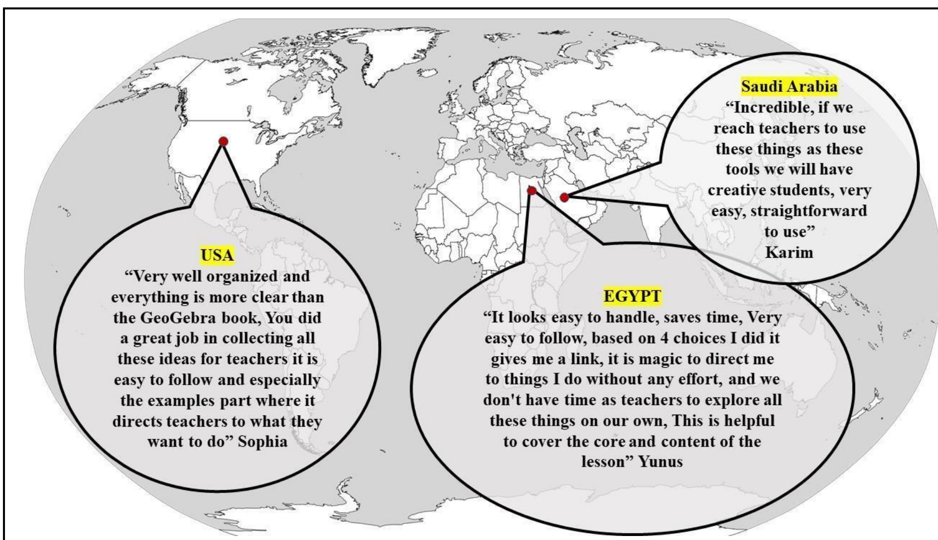

Fig. 4 Teachers cross-culturally describing the DLP tool feature

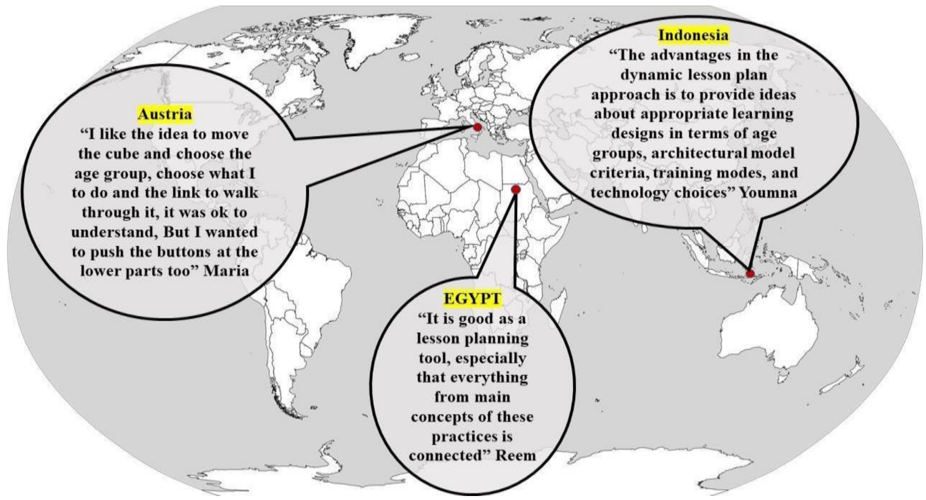

Fig. 5 Teachers cross-culturally describing the DLP tool advantages

Cross-culturally, teachers found the DLP tool structure to be an *"understandable", "appropriate lesson planning tool"* that supported the selection of age-appropriate practices for architectural modelling and *"helps teachers to structure the STEAM practices lesson planning"* as can be seen from the interview responses of Maria from Austria and Reem from Egypt and questionnaire responses of Youmna from Indonesia (Figure 5).

The second theme that emerged from the analysis indicated that ***the DLP tool helped teachers to learn about technology***. This is evidenced from the responses to the questionnaire by Indonesian teachers (Figure 6).

From our observations during the teachers' explorational phase of the DLP tool during the PD, we noticed that teachers' curiosity was substantial to learn about the technology used which appeared in their inquiries that was focused on technological tools presented

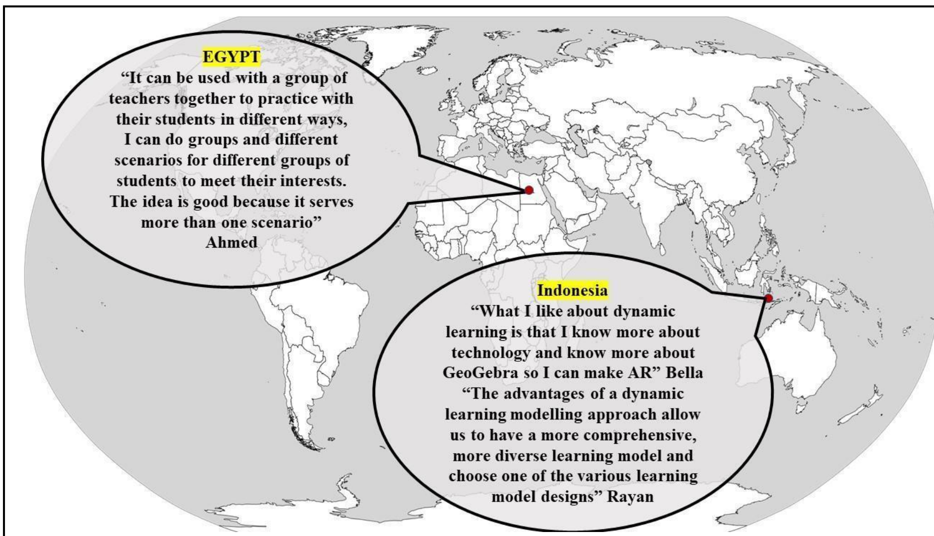

Fig. 6 Teachers cross-culturally describing the DLP tool teaching and learning benefits

as options inside the DLP tool such as digital and physical tools (e.g., GeoGebra AR, 3D printing, 3D scanning, Origami ...). Therefore, teachers were curious about how to integrate the DLP tool technologies in their teaching and learn more about them. Furthermore, the DLP tool is availed to teachers as a web-based tool that could allow them to create their lesson on digital platforms instead of traditional paper and pen techniques. In addition, the DLP tool connects teachers to a heuristic GeoGebra book with detailed steps and examples of how to apply and utilize each of its components and technologies.

Finally, the third theme that emerged from the analysis shows that ***some teachers found the DLP tool helpful for collaborating with other teachers***. For example, in an interview, an Egyptian teacher indicated that a group of teachers could use the DLP tool together while customizing STEAM practices to meet diverse student learning needs (Figures 5 and 6).

Teachers recommended DLP tool for students' uses

One of the most interesting comments we received from most of the interviewed teachers is that they asked if the DLP tool is for teachers' use or students' use. From this question, we interpreted that some teachers were willing to share this tool with their students. Therefore, we integrated this question into our semi-structured interview protocol and questionnaire. Based on the analysis of teachers' answers to this question, the following themes emerged ***offering the DLP tool for students to use in order to increase their motivation towards learning mathematics***. Moreover, teachers indicated that ***if students use the DLP tool, they are able to explore and learn technology***. These two themes were evidenced by a response to the questionnaire by teacher Bella from Indonesia (Figure 7).

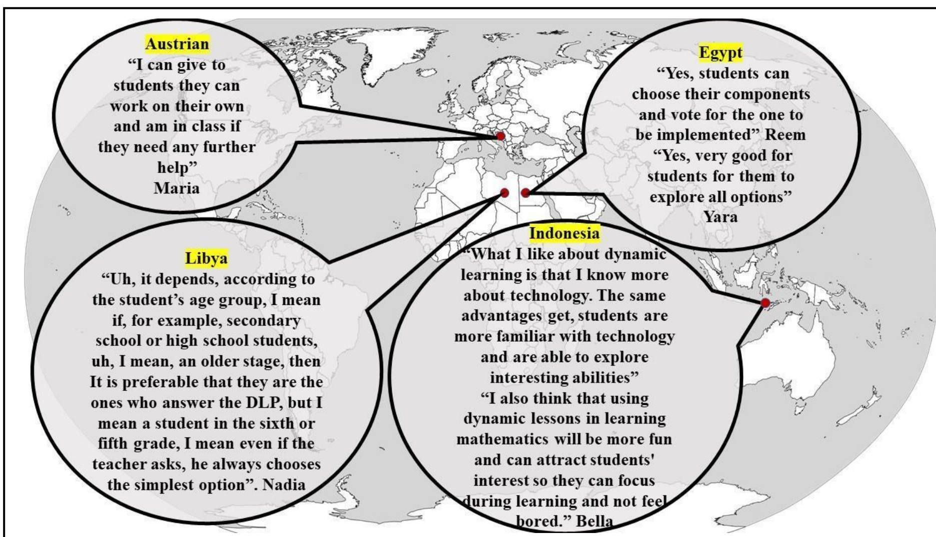

Fig. 7 Teachers responding to students' use of the DLP tool

Moreover, teachers indicated that the ***DLP tool could allow students to work independently***, as evident from the interview responses of teachers from Austria and Egypt (Figure 7). As well as ***the DLP tool allows students' explorations***; as evident from the interview response from Egyptian teachers (Figure 7).

However, other teachers had some concerns about sharing the DLP tool with students and they suggested that ***providing the DLP tool to students is dependent on their ages*** in order to use the tool appropriately and gain the required learning outcomes as evident from Libyan teachers' interview response (Figure 7).

Moreover, Austrian and Egyptian teachers mentioned in their interview, ***that the DLP tool could aid in applying some teaching methods*** they are using as inquiry-based learning (IBL) and flipped classroom approaches (Jung & Hong, 2020). Where they believed the DLP tool could help them in applying IBL and flipped classroom approaches by introducing the DLP tool to their students, which could allow students to explore technologies and learn independently.

We will now explore what were the emerged themes that were based on teachers' recommendations for the DLP tool.

Teacher's recommendation for the DLP tool cross-culturally

We asked teachers to recommend enhancements to the DLP tool, hence, we present the themes that emerged from the analysis of teachers' collected data from various countries who provided suggestions for improvements of the DLP tool to become a cross-cultural tool for lesson planning.

Based on the analysis, we divided teachers' recommendations into two general categories – non-culture-specific and culture-specific recommendations about DLP design, content, presentation and culture-specific recommendations.

Non-culture-specific recommendations

The majority of the participating teachers didn't face difficulties using the DLP tool despite their cultural differences. Teachers' non-culture-specific recommendations for the DLP tool included design enhancements such as selecting the fonts and colors, adding notes to the UI buttons and content enhancements such as adding instructions for teachers, providing explanatory videos for teachers on how to use the tool, providing feedback or assessment criteria in the DLP tool, including age choice for older than 16 years old students. The excerpts from teachers' interviews and questionnaire responses that support these results are provided on Figure 8.

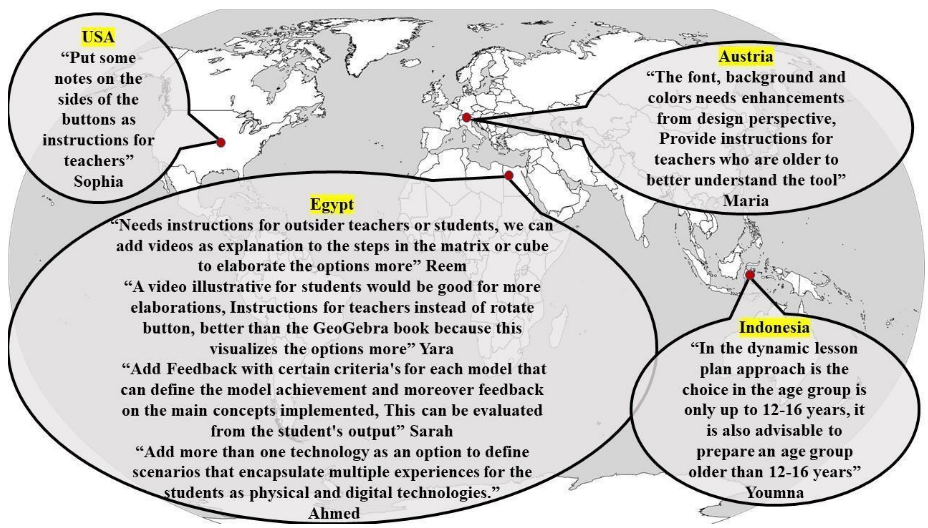

Fig. 8 The non-cultural teachers' recommendation for the DLP tool

Culture-specific recommendations

Four teachers from Austria, Saudi Arabia, and Egypt recommended some customizations to the DLP tool that were culturally bounded, such as language choice, the direction of presentation of DLP elements, alignment with local curriculum and lesson plan requirements. This is evidenced by the examples of interview excerpts shown in Figure 9. Maria, the teacher from Austria, commented that it was unusual for European countries to UI elements directions in the DLP tool, while Karim from Saudi Arabia recommended including an option to choose language preferences in the tool. Ahmed and Laura, both teachers from Egypt, recommended changes that were very specific to their local curriculum and lesson plan requirements, as can be seen from their interview excerpts.

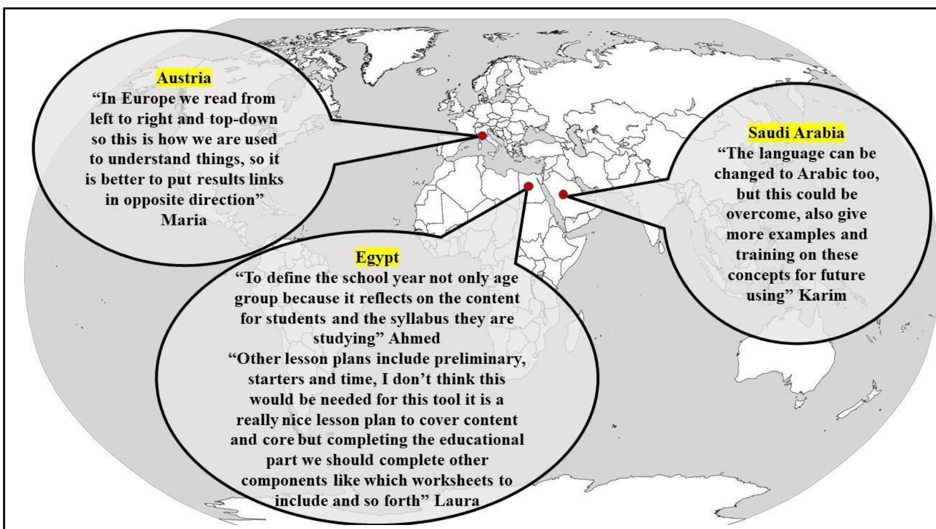

Fig. 9 Showing some cultural-related teachers' recommendations

DLP tool support for STEAM practices

We now discuss participating teachers' preferences for the DLP tool during the PD workshops of these STEAM practices. Three themes emerged from analyzing teachers' preferences: the first one was ***teachers used the DLP tool in different ways and incorporated various components that resulted in various lesson combinations during their learning about these STEAM practices***. A variety of options included in the DLP tool resulted in lesson plans that used various approaches to teaching mathematics, for example, modern architecture modelling, AR technology that was implemented in a museum learning environment, etc. The second theme that emerged was ***teachers applied transdisciplinary approaches by connecting these STEAM practices to culture, history, mathematics, arts and architecture***. Teachers connected several disciplines while implementing these STEAM practices, thus denoting these practices could apply cross-disciplinary approaches into learning. For example, teachers collected cultural and historical information about selected architectures and reflected on architecture artistic elements including forms, shapes, symmetries, etc. that they presented as part of these STEAM practices outcomes. The third emerging theme was ***the diversity in the architecture choices reflecting the diverse teachers' groups and cultural backgrounds that participated in this study***. During the analysis of the teachers' architectural modelling outcomes, we noticed the diversity amongst the architectural model choices, this reflects the diversity of the group of participants we were dealing with, and it reflects how these STEAM practices implementation could be used to express diversity. For example, some teachers used architecture that reflected their cultural backgrounds, while others favoured a broader approach towards their architectural choices as architecture from other cultures. Hence, this reflected architectural and cultural diversity in the study outcomes. These three emerging themes (Figure 10), show how the DLP tool can result in diverse outputs due to the diverse components and options available to teachers.

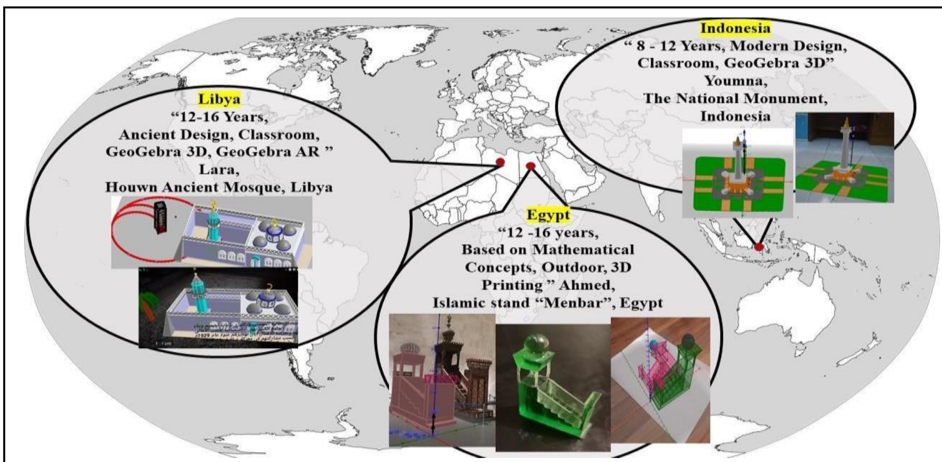

Fig. 10 Examples of teachers' preferences of the DLP tool components from the PD

At the same time, the variety of the architecture choices reflects the diversity in cultural backgrounds of the teachers who participated in this study. These findings address the second research question. These findings indicate how the DLP tool can result in diverse results due to the flexible components and options available to teachers, as teachers can freely choose to integrate any of the available components in their lesson plans. Examples of those teacher-produced artefacts demonstrate diversity not only in architectural choices but also in learning environments and/or technological choices (Figure 10). Figure 10 illustrates how teachers adopted the DLP tool for these STEAM practices to be used in their specific cultural environments.

The selected examples connect to teachers' preferences from the DLP tool components during the PD. Hence, we used triangulation between the different data sources to resemble the similarities and differences between the teachers' DLP tool preferences at the beginning of the PD workshops and their PD outcomes. This reflected how similar were the teachers' DLP tool preferences in both cases, this could denote that the DLP tool can contribute to the teachers' own learning which could be reflected in their future teaching by constructing transdisciplinary STEAM practice lesson plans. In the coming section, we will see the implementation of the teachers' recommendations for the DLP tool.

DLP tool enhancements

We received several suggestions and recommendations from the participating teachers for the DLP tool. Hence, we intend to update the DLP tool to address the participating teachers' recommendations and suggestions for enhancing the DLP tool design. Therefore, according to the emerging themes that we discussed in the last section, we chose to apply the non-cultural teachers' recommendations for the DLP tool to maintain the DLP tool's cross-cultural nature. Likewise, teachers could use the DLP tool regardless of their cultures, to maintain the DLP tool as a universal lesson planning tool that addresses these STEAM practices. Therefore, we applied the following changes in the DLP tool enhanced version according to the teachers' non-cultural recommendations, we included a prescriptive text on the DLP tool aims and instructional steps on why and how to use the DLP tool in the first scene the users open. This step was recommended by the teachers, to allow the DLP tool to be shared by other teachers who didn't participate in the PD training and thus require general information on the tool and instructions on how to use it (Figure 11).

Teachers recommended adding another category under the students' age group to allow the selection of students older than 16 years old to consider applying the DLP tool for university students and specifically for pre-service teachers. We updated the technological preferences in the DLP tool based on the experience we gained from applying several technologies in the research iterative cycles with participants during the PD for visualization and modelling purposes of architectural constructions. Moreover, we

Fig. 11 DLP tool first scene with information and instructions

enhanced the UI/UX design of the UI elements in the DLP tool to provide a better interface for teachers, based on the participating teachers' recommendations.

We added other discipline connections to explicitly allow teachers to implement the transdisciplinary STEAM practices. Hence, enabling teachers to select explicit preferences for cultural, historical, geographical and artistic connections in the DLP tool (Figure 12).

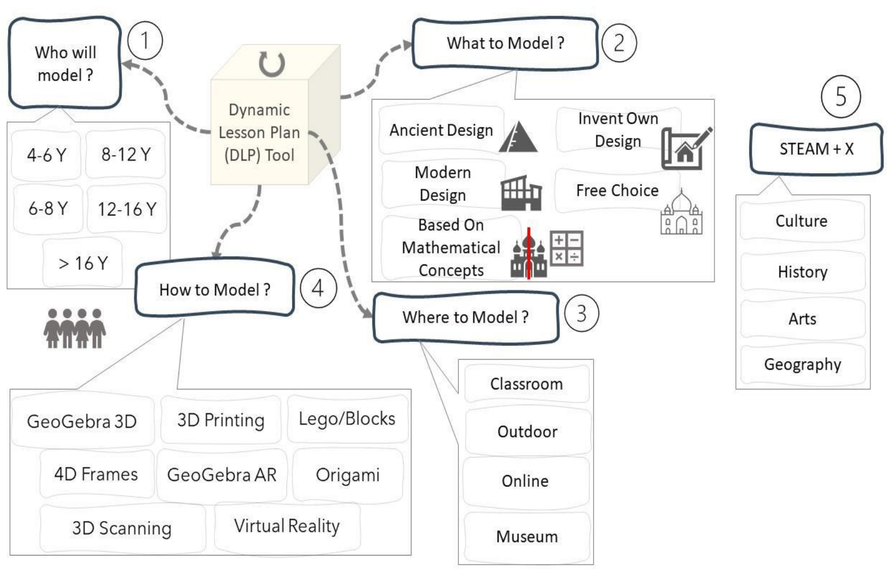

Fig. 12 The DLP tool enhanced version components

Although this enhancement wasn't a recommendation from any of the participating teachers, we felt the urge to include it based on our observations from the iterative cycles and working with teachers. During the PD workshops, we advised the teachers to connect to cultural and historical connections of architecture and find out other possible discipline integrations while implementing these STEAM practices. However, if teachers distribute the DLP tool to their colleagues without direct training, then it could be possible that they wouldn't notice the implicit transdisciplinary nature of these STEAM practices outside of integrating architecture explicitly.

Therefore, the option of including other disciplines was added to emphasize the transdisciplinary nature of these STEAM practices, and explicitly highlight it in the DLP tool. Moreover, these enhancements to fostering transdisciplinary in the DLP tool could allow collaboration between teachers from diverse disciplines to work on a common lesson preparation tool to implement STEAM practices collaboratively (Figure 13).

When teachers define all the lesson criteria from all the components including the discipline integration selections, afterwards, they are guided to customized links to redirect participants to the GeoGebra book. The GeoGebra book, as part of the design heuristic of this study, was also updated. We added a prescriptive description of each criterion in the DLP tool including implemented examples that were implemented by the participating teachers during the PD. Furthermore, participating teachers' final projects and architectural models were included in the GeoGebra book as heuristic examples. The STEAM practices' final project outcomes implemented by teachers could guide other teachers in the

Fig. 13 The DLP tool web interface enhanced functionalities

implementation of these practices because these outcomes provide real examples of these STEAM practices. Therefore, we added the following examples captured from teachers' STEAM practices: modelled architectures (Figure 14), technology visualization and discipline connections (Figure 15).

Fig. 14 Screenshots from the GeoGebra book of architectural modelling results of two Libyan teachers

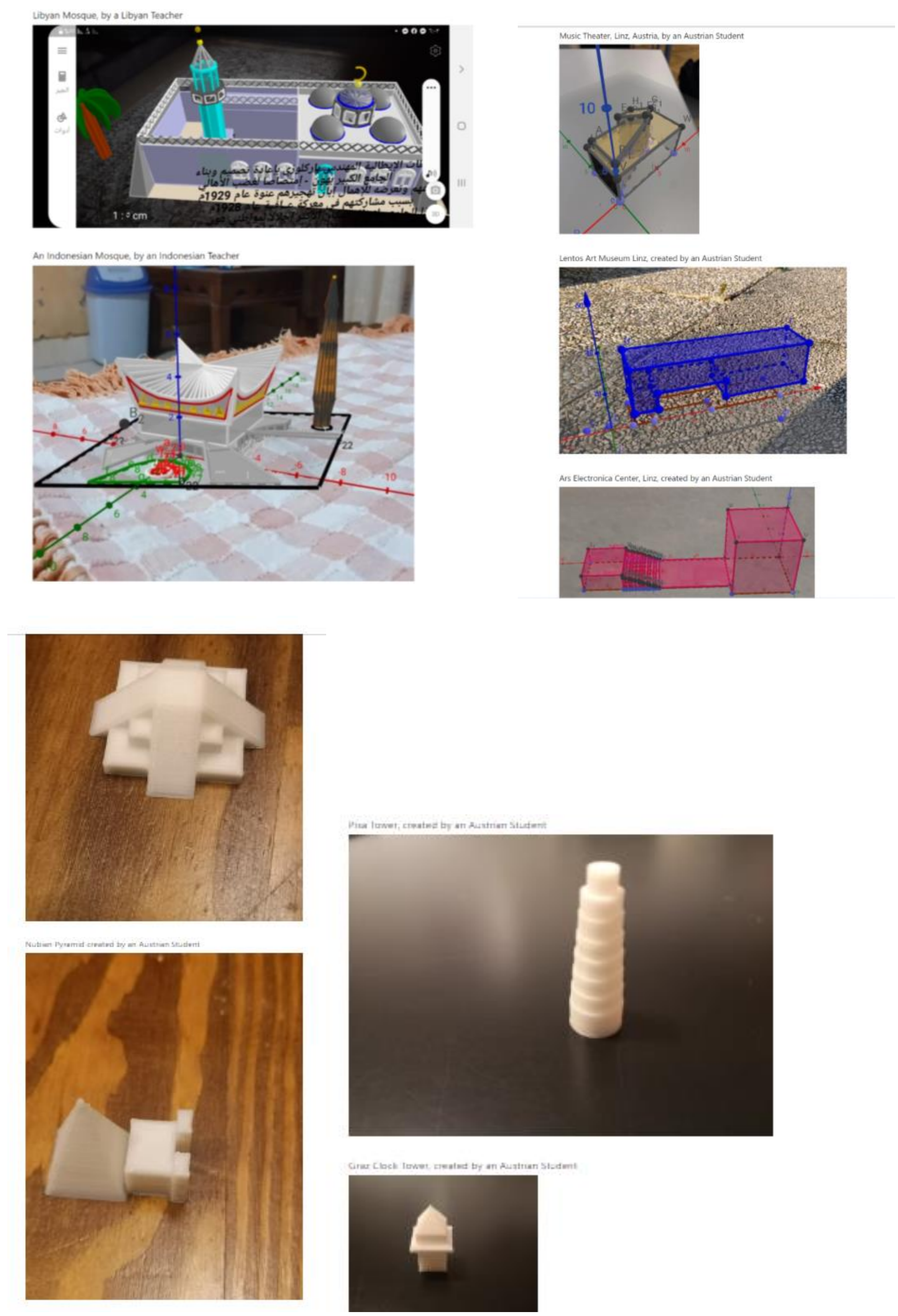

Fig. 15 Screenshots from GeoGebra book showing the GeoGebra AR and 3D printing visualization examples

The participating teachers' final projects show the transdisciplinary connections between architectural modelling, cultural and historical connections as stated in the examples provided in the GeoGebra book. These examples could foster transdisciplinary connections with other teachers using the DLP tool.

Discussion

The themes that emerged from the analysis of interviews, questionnaires, and artefacts collected from teachers contributed to the findings of this study. In this section, we will interpret the relationships between these themes and their relations to lesson plan development literature.

Teachers expressed a positive attitude towards the DLP tool features and structure. This could be due to the flexibility of the DLP tool (Strickroth, 2019), and to the several options provided under each category to meet the participants' personal preferences or cultural diversity. Moreover, we wanted to provide teachers with possibilities in order for them to personalize their DLP tool experience and to meet their teaching needs (Caton, 2021). Therefore, the DLP tool didn't restrict teachers' options and provided possibilities of selecting the students' age, architecture, learning environments or technologies. Hence, we tried to keep the DLP tool components simple, by categorizing four main ones that teachers could choose from to complete their transdisciplinary STEAM practices lesson planning.

Teachers used the DLP tool during their PD in different ways and incorporated various components. DLP tool includes a wide spectrum of technologies, learning environments, and architectures. The DLP tool provided teachers with several options under each component to overcome any affordance when it comes to technology or learning environments (Demir, 2011). In addition, we noticed that teachers were interested in the DLP tool's multiple options under each component. Hence, we deduced that when teachers are provided with multiple options for STEAM practices implementation, this can provide teachers with flexible possibilities for technological and learning environment choices and future explorations for their learning and teaching (Demir, 2011). Moreover, this feature of providing teachers with multiple options in the DLP tool could allow them to produce multiple versions of the same lesson to address the needs of diverse students and learning situations (Cicek, 2013).

The findings show that teachers didn't find any cultural obstacles to using the DLP tool. Instead, teachers' artefacts show that they adapted and connected these transdisciplinary STEAM practices to their cultures, by choosing architectural examples that have personal cultural meaning and significance. The other two DLP components depended on the availability to teachers that impacted their learning environments or technological choices. The teachers' outcomes show that teachers used various learning environment options varying from online, classroom, and museum that best suits their affordable learning environments. Moreover, the teachers' artefacts show that teachers chose various technologies that were accessible to them during their PD. DLP tool could aid teachers in advancing their technological knowledge, following Demir's (2011) recommendations, to include various technologies to overcome participants' technology affordance and to propose new technological learning. In addition, it could be thought of that the DLP tool has an interactive, dynamic nature that is easily accessible through the web, we could assume these features allowed teachers to consider it a useful and effective lesson planning tool. All these various lesson combinations based on four components and the fact that participating teachers were culturally diverse, shows how teachers can implement these transdisciplinary STEAM practices cross-culturally (Winsløw et al., 2018). Afterwards, teachers could be redirected to their preferences in the GeoGebra book. We tried to ensure the simplicity of the lesson planning process to overcome any time-consumption problems for teachers (Srikoom, 2021). Hence, we tried to follow Caton’s (2021) advice by bridging the gap teachers face between choosing an inquiry and how to implement it, by providing extra heuristic examples to teachers through the GeoGebra book or through the PD workshops. Therefore, the study design heuristics could aid teachers in lesson planning and implementation of these STEAM practices through the DLP tool and GeoGebra book.

DLP tool features were guided by the theoretical frameworks that we utilized in this study, AMOBA and Milkova to ensure lesson planning and cultural considerations. The DLP tool was guided by Milkova’s recommendations for defining the main components of a lesson plan and helped us provide activities to support teaching/learning objectives, for teachers to construct their lessons and to define which components are essential to cover the content of transdisciplinary STEAM practices represented in the DLP tool. The AMOEBA framework was used to aid in the design and implementation of the DLP tool cross-culturally. Culturally specific design features suggested by Gunawardena et al. (2003) were taken into consideration in planning the PD workshops for diverse teachers from various countries and regions. Therefore, following AMOEBA resulted in diverse immersive experiences that respected the teachers’ cultural differences. Teachers’ cultural diversity helped us get diverse feedback about the DLP tool and support its development. Hence, the DLP tool is an attempt to encapsulate a cross-cultural sharable lesson planning tool. Moreover, the DLP tool as a design heuristic assisted the teachers in their PD workshops to understand STEAM practices in theory and in practice.

The teachers suggested that the DLP tool could increase students’ motivation to learn mathematics by allowing students to freely explore all the possibilities which the DLP tool provides to implement these STEAM practices. Hence, these findings could help teachers to apply teaching methods that foster students’ exploration, inquiry, and creativity (John, 2006). Therefore, these teaching methods when applied could encourage students to combine architecture, culture, and history in mathematics education (John, 2006).

Teachers also suggested that the DLP tool can support integration between different disciplines to apply these STEAM practices as architecture, culture, history, arts, technology, engineering and mathematics (Guyotte et al., 2014). The DLP tool allowed teachers to plan diverse scenarios that could stress various disciplines’ integration and could be adapted to various learning goals. These scenarios were focused on integrating architecture, culture, history to STEAM practices in the form of mathematical modelling tasks using GeoGebra. Therefore, we consider the work presented in this study as an approach to utilizing the DLP tool, that can be further utilized in various ways by integrating other disciplines and other technologies that could be guided by the teachers learning goals. Hence, the DLP tool could be interpreted as a tool that allows teachers to propose various integrated lesson plans (Srikoom, 2021). Therefore, we can argue that the DLP tool could be considered a universal tool to aid teachers in planning for transdisciplinary STEAM practices implementation and spread cross-culturally.

Conclusions

This paper proposes a cross-cultural DLP tool to enable teachers to plan lessons based on transdisciplinary STEAM practices. The proposed STEAM practices may allow participants to mathematically model architecture using GeoGebra. Moreover, these practices could connect mathematics learning to the culture and history of these architectures. In this study, we developed a web interface, the DLP tool, for teachers to aid them through the process of planning the proposed STEAM practices. The DLP tool provides teachers with various options to implement these practices and to make their lessons culturally relevant. The diverse options presented in the DLP tool enable teachers to choose from four components that could suit them in their teaching and learning cross-culturally. From the teachers' artefacts, we could see how the DLP tool components can be encapsulated, how the four components blend and mix, and how the teachers understand these lesson plans' possibilities. Moreover, it shows how teachers can promote creativity, problem-solving, and reasoning from these STEAM practices.

Further research is needed to explore the DLP tool-enhanced version with teachers and carry out another iterative cycle with possibly culturally diverse participants to examine the tool's cultural sustainability. Moreover, we are eager to explore the DLP tool and how teachers implement STEAM practices with their students and to capture the outcomes of these experiences. For instance, how and why can teachers integrate these practices into the courses they are teaching in their schools? How and why can teachers from various disciplines collaborate to implement such practices? What are the differences between in-service/pre-service teachers' outcomes and if their age of taught students also makes a difference? Answers to these questions are unique from one teacher to another and could reflect the teachers' creativity in using the given tools. These questions are part of our future plans in seeing the results from teachers who participated in the teachers' PD workshops cross-culturally. We assume the DLP tool may result in a different experience for learning and teaching than the traditional lesson planning design to apply transdisciplinary STEAM practices. Accordingly, we recommend that STEAM practices sharable cross-cultural DLP tool could guide teachers in its implementation and could be adopted in different settings.

Abbreviations
AMOEBA: Adaptive, Meaningful, Organic, Environmental-based architecture for Online course design; AR: Augmented reality; DBR: Design-based research; DLP: Dynamic lesson plan; IBL: Inquiry-based learning; PD: Professional development; STEAM: Science, Technology, Engineering, Arts & Mathematics; UI: User interface.

Authors' contributions
The corresponding author is responsible for the whole manuscript software implementation writing. The second and third author edited, read and approved the final manuscript.

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