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Authentic problems of knowledge society: mathematics teachers' integration of cognitive and social dimensions into stem lesson plans

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Regarding the teachers' key role in shaping students' STEM education experiences through their instructional designs, our research focused on how mathematics teachers integrate social and cognitive dimensions into their STEM lesson plans. We used document analysis to study the STEM lesson plans of mathematics teachers (n=34). The results showed that mathematics teachers mostly included communication and collaboration with others in their lesson plans for learning and innovation skills. Most teachers integrated cognitive and social dimensions and provided flexibility in solutions. However, teachers struggled to integrate an original context into the problems. Integrating other disciplines into the Authentic Problems of Knowledge Society (APoKS) was also a challenge for mathematics teachers. More research is needed to explore the contextualisation and interdisciplinarity of mathematics topics to improve students' critical thinking and problem-solving skills.

Keywords: Mathematics teachers, STEM education, teachers' professional development.

Introduction

The complex and dynamic problems of today's society require individuals to contribute to solving them. People from different disciplines are also actively involved in producing scientific knowledge. STEM education aims to bring a well-rounded perspective to the complex and nested problems of today's world by combining knowledge and skills from the disciplines of science, technology, engineering, and mathematics (Corlu, 2017). In most countries, STEM education is linked to the need to educate individuals with skills and knowledge in STEM disciplines (Oner & Capraro, 2016; Partnership for 21st Century Skills, 2017).

Research showed that mathematics teachers have difficulties integrating other disciplines into their STEM education practices (Lesseig et al., 2016; Stohlmann, 2018). Mathematics has been evaluated as having one solution for its problems, and teachers mostly concentrate on this solution rather than the process (Sitorus, 2016). Researchers and teacher educators also recommended using more contexts in mathematics education so that students can engage in complex problem-solving (Choi & Hannafin, 1997; Lowrie, 2005). However, most mathematics teachers reported being underprepared to include relevant contexts in their STEM lesson plans (Aydın & Özgeldi, 2019). Following this research evidence, it is critical to study mathematics teachers' STEM integration preferences and practices.

Literature review

Regarding the key role of context in STEM education, it is necessary to consider social, cultural, political, and economic factors and to work across different disciplines to find alternative solutions to contribute to solving the world's problems (Root et al., 2018). In addition to cognitive outcomes, the integration of social skills is also crucial in the pursuit of scientific information. Integrating social and cognitive dimensions through authentic societal problems allows students to see their societal role from a broader perspective (Hall & Jurow, 2015). Students and teachers can then integrate equity and social justice issues into STEM disciplines.

In this research, the theoretical framework is based on an integrated approach to linking different purposes of STEM education. In the integrated STEM education framework, the fundamental principles of equity and relevance are linked to the consideration of each student's interests and life experiences, while interdisciplinarity and rigor are linked to the inclusion of other disciplines without losing the focus and rigor of the central discipline (Figure 1). The overarching goals are placed in the outer circle of the framework (Corlu, 2017).

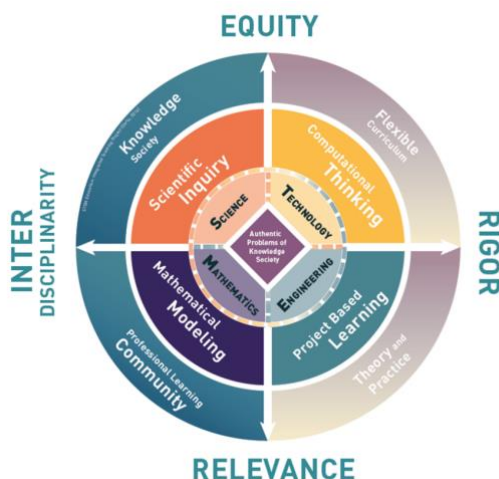


Figure 1: STEM: Integrated Teaching Framework (Corlu, 2017)

At the centre of the framework are Authentic Problems of the Knowledge Society (APoKS). The APoKS is defined as "an open-ended problem with a scenario specific to the conditions of the 21st century, which should be solved by developing authentic strategies and products taking into account the limitations of the problem" (Yabas & Corlu, 2021). Most importantly, ill-defined tasks indicate tasks with a scenario that attracts students' interest, sets a stage and presents in-depth knowledge of the scenario or problem, which implies good preparation for teachers (Capraro & Corlu, 2013).

The previous research focused on mathematics teachers' views, knowledge, and skills in STEM education. However, there is a significant need to gather more in-depth evidence on teachers' STEM lesson plans. Exploring the potential of teachers' STEM lesson plans to provide students with cognitive and social skills is expected to contribute to the literature on STEM education.

Given the key role of teachers in shaping students' STEM educational experiences through their lesson designs (Diefes-Dux, 2014; Nadelson et al., 2012), our research focused on two research questions to explore mathematics teachers' STEM lesson plans:

1. Which social skills did mathematics teachers include in their STEM lesson plans?
2. How did mathematics teachers integrate cognitive and social dimensions into their STEM lesson plans?

Methods

In this qualitative study, the participants were mathematics teachers who completed a year-long STEM Leader Teacher Professional Development (PD) Program. The PD program started in 2016 to provide a sustainable and research-oriented in-service teacher PD on integrated STEM education. This program promotes a sustainable interaction between teachers, teacher educators, and academicians to provide a comprehensive PD that takes approximately eight months and 92 hours, including digitally recorded workshops, online theoretical and practical lessons, and interactive tasks. The program includes four quarters focusing on each STEM discipline and how the corresponding teaching approach could be integrated with the other STEM disciplines. Participants were 34 mathematics teachers who completed the PD program in the 2020-2021 academic year. Most of the teachers were female (71% female, 29% male).

Data for this study included participants' STEM lesson plans, in which they submitted their implemented lesson plans at the end of the STEM Leader Teacher PD Program. Participants were provided with the STEM learning cycle + line and the STEM lesson plan template. The STEM lesson plan template was shaped by the principles of the STEM integrated teaching framework and was developed by STEM education researchers and teachers (Corlu, 2017).

For data analysis, the authors individually scored the participants' STEM lesson plans using the STEM lesson plan evaluation rubric. Some criteria are given in Table 1. The rubric was developed by STEM education researchers to provide a framework for evaluating STEM lesson plans, and the rubric has been tested on over 1000 STEM lesson plans. During the PD program, this rubric was shared with participants and explained in detail to inform them of the scoring criteria. In this study, the APoKS part of the rubric was used to answer the research questions. Nevertheless, the other sections of the lesson plans were also analysed for a holistic picture of the authentic problem.

We also used the Framework for 21st Century Learning (Partnership for 21st Century Skills, 2019) to explore the social skills that mathematics teachers included in their STEM lesson plans. This framework identifies the skills and knowledge that students are expected to develop during learning experiences. All authors independently analysed the lesson plans using the STEM lesson plan scoring rubric. The authors compared coding results between reading episodes and discussed coding categories until full agreement was reached. To achieve complete consensus, 10% of the lesson plans were coded in tandem via an online meeting platform while the remaining lesson plans were disseminated among the coders. During subsequent meetings, the researchers aggregated their respective coding outcomes and collectively deliberated to resolve any areas of ambiguity before finalizing the coding process.

Table 1: STEM lesson plan evaluation rubric for APoKS (sample criteria)

Categories	Poor/ Unacceptable	Needs improvement	Acceptable	Excellent
The originality of the authentic context	APoKS do not exist or APoKS and lesson content do not match	APoKS has a weak relationship with real life and 21st century contexts	A non-authentic APoKS is chosen that is narrated in contexts of 21st century	A unique APoKS has been determined in the 21st century context
Flexibility of the problem for alternative solutions	APoKS is not designed to guide students to develop different products	APoKS is limited to guide students to develop different products	APoKS guides students to develop different products	APoKS is written that can have multiple solutions or let students manipulate multiple variables
Integration of cognitive and social aspects	APoKS does not include social product and cognitive process	APoKS limitedly include social product and cognitive process	APoKS includes social product and cognitive process	APoKS clearly includes social product and cognitive process coexistence
Interdisciplinarity	APoKS does not offer the opportunity to use the knowledge and skills of more than one STEM discipline	APoKS does not clearly offer the opportunity to use the knowledge and skills of more than one STEM discipline	It is clear that knowledge and skills from more than one STEM discipline will be needed.	It is clear that knowledge and skills from multiple STEM disciplines will be needed.

Findings

Regarding the first research question, we analysed the social product outcomes in the lesson plans to determine the social skills that mathematics teachers included in their STEM lesson plans. Teachers included social outcomes alongside the cognitive outcomes related to STEM disciplines. Using the P21 framework for 21st-century learning, we analysed which 21st-century skills were addressed in the social outcomes. As can be seen in Table 2, learning and innovation skills were the most frequently mentioned skills in the lesson plans. Communicating clearly and collaborating with others had the highest frequency, while critical thinking and problem-solving, specially making judgments and decisions and using systems thinking, had the lowest frequency. Teachers' lesson plans focused more on communication and collaboration than on critical thinking and problem-solving. Within life and career skills, only one teacher used to be self-directed as an outcome of the initiative and self-direction subskill.

Regarding the second research question, we used the STEM lesson plan evaluation rubric to explore how mathematics teachers integrated cognitive and social dimensions into their STEM lesson plans. Regarding originality of the authentic context, most of the APoKS in the lesson plans were coded as acceptable which indicated that the problems were narrated in 21st-century contexts (70.6%). For example, one of the mathematics teachers in her ApoKS has created the setting of a job interview in an architect's office:

You are a final year student at Bahçeşehir University Faculty of Architecture, Gensler Architecture Firm, one of the largest architecture companies in the world, located in the USA, which is among

the companies you applied to work abroad, asked you to design a large and interesting meeting room and make your presentation online. Let's see what kind of design you will make. Geometric shapes should be prioritised in the design.

Table 2: The social outcomes in mathematics teachers' STEM lesson plans

Skills	Subskills	Outcomes	Frequencies
Learning & Innovation	Communication and collaboration	Collaborate with others	29
		Communicate clearly	23
	Creativity and innovation	Think creatively and work creatively with others	5
	Critical thinking and problem-solving	Solve Problems	7
		Use system thinking	2
		Making judgments and decisions	1
Life & Career Skills	Initiative and self-direction	Be self-directed	1

Teachers mostly used different resources to describe the context. However, some of the APoKS were identified as needing improvement (20.6%) because of the weak relationship of the APoKS to real-life and 21st-century contexts. In addition, in three lesson plans, the outcomes of the lesson plans and APoKS did not match.

The second criterion for evaluating the APoKS was the flexibility of the problem for alternative solutions. Concerning the flexibility of the problem for alternative solutions, the APoKS in most lesson plans was evaluated as acceptable, which indicate that lesson plans led the students to develop different products to find solutions to the described problem (76.5%). One of the mathematics teachers focused on animal nutrition as an example of an ill-defined problem that encourages alternative solutions. She framed her APoKS as

Ms Seda, who has two cats, one 12 years old (Alice) and the other two years old (Gren) and will start using special food for obese cats for her 12-year-old cat Alice on the recommendation of the vet. Gren eats adult cat food. At the same time, Ms Seda, who took a 2-month-old kitten she found in her garden into her house and named her Chia, bought kitten food for her little guest. Can you help Ms Seda, who does not prefer free-feeding for all three cats and will feed them with meals? How many grams of food should she feed which cat in the morning and evening?

As far as the flexibility of the problem is concerned, we found that a significant percentage (23.5%) of the lesson plans contained a well-defined problem with a single solution.

The third criterion for evaluating the APoKS was the integration of cognitive and social dimensions. Regarding the integration of cognitive and social dimensions, the APoKS in most lesson plans included the coexistence of social product and cognitive process (94.1%). Teachers often asked students to work in groups and framed the group work around relevant real-life STEM careers.

The fourth criterion used to evaluate the APoKS was interdisciplinarity. Most APoKS required knowledge and skills from several STEM disciplines (67.6%) regarding interdisciplinarity. As an example of a lesson plan that paid attention to interdisciplinarity, one APoKS focused on protection from coronavirus. She included explicit objectives from science and technology disciplines:

People worldwide have started to take measures to protect themselves from the coronavirus. According to the statements made by the authorities, we should wash our hands when we come into contact with a place or use disinfectants when we cannot wash our hands. It is also said that the disinfectants used in the statements made by the authorities should contain a certain alcohol content to be effective. Ms. Neslihan goes to the pharmacy to buy a reliable disinfectant to use when she cannot wash her hands and examines the products. She heads towards the disinfectant aisle that the pharmacist can recommend. Ms. Neslihan is confused about choosing when she sees many products in the aisle. I want you to design a game that makes it easier for Ms. Neslihan to select the appropriate products.

A significant percentage of the lesson plans (32.4%) did not include an interdisciplinary context in their APoKS, like the flexibility criterion.

Discussion

The results showed that mathematics teachers mostly included communication and collaboration with others in their lesson plans for learning and innovation skills. However, teachers placed less emphasis on critical thinking and problem-solving. The literature indicates the importance of solving problems, making plausible judgments, and using systems thinking skills (Ford, 2015; Sinatra & Lombardi, 2020). This indicates a need for teacher preparation programs and PD which provide more experiences to promote critical thinking and problem-solving skills (Yabas & Corlu, 2021).

Life and career skills were also less frequently observed in lesson plans. Few teachers included flexibility and adaptability, and initiative and self-direction skills. One explanation is that teachers tend to focus on improving students' knowledge of mathematics content. However, it is known that 21st century and expert thinking skills are expected from individuals in the workplace as the demand for mundane skills decreases (Levy & Murnane, 2012). Therefore, mathematics education researchers emphasise that mathematics education should include cognitive, social, and generic skills through problem-solving (English & Gainsburg, 2016). Mathematics education should help students to meet the demands of both work and everyday life (Gravemeier et al., 2017).

Interdisciplinary connections were less common in maths teachers' STEM lesson plans. It may be that mathematics teachers are not used to making interdisciplinary connections. Few researchers have studied the theoretical and conceptual aspects of interdisciplinarity in mathematics (Williams et al., 2016). When teachers try to integrate mathematics in interdisciplinary contexts, mathematical concepts and skills are mostly in a service role, and students cannot engage in meaningful mathematical practices (Barnes, 2000). With a participatory approach to teaching and meaningful interdisciplinary connections, teachers are able to highlight the significance of mathematical concepts and skills (Tytler et al., 2019).

The results showed that most teachers integrated cognitive and social dimensions and provided flexibility in solutions. However, teachers struggled to integrate an original context into the problems. Integrating other disciplines into the APoKS was also a challenge for mathematics teachers. Teachers should focus more on contextualised teaching to promote deeper learning (Root et al., 2018).

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