Technology-mediated lesson study: a step-by-step guide

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Received 11 July 2023
Revised 6 November 2023
11 December 2023
Accepted 12 December 2023

Abstract

Purpose – The authors are developing a model for rural science teacher professional development, building teacher expertise and collaboration and creating high-quality science lessons: technology-mediated lesson study (TMLS).

Design/methodology/approach – TMLS provided the means for geographically distributed teachers to collaborate, develop, implement and improve lessons. TMLS uses technology to capture lesson implementation and collaborate on lesson iterations.

Findings – This paper describes the seven steps of the TMLS process with examples, showing how teachers develop their content and pedagogical knowledge while building relationships.

Originality/value – The TMLS approach provides an innovative option for teachers to collaborate across distances and form strong, lasting relationships with others.

Keywords Lesson study, Technology-mediated lesson study, Teacher professional development, Three-dimensional science, TMLS method

Paper type Research paper

This work is funded by the National Science Foundation under (No: DRL-2101383). Any opinions, findings, conclusions or recommendations expressed are those of the authors and do not necessarily reflect the views of the National Science Foundation.

International Journal for Lesson & Learning Studies
Vol. 13 No. 5, 2024
pp. 1-14
Emerald Publishing Limited
2046-8253
DOI 10.1108/IJLLS-07-2023-0094

Introduction

Rural teachers are professionally isolated, and science teachers may be the only educator of a specific content area within their school (Burton *et al.*, 2013). Additionally, rural teachers are geographically isolated from opportunities for professional learning and have increased responsibilities such as coaching and administration (Biddle and Azano, 2016). The combination of professional isolation, lack of access to development opportunities and substantial responsibilities leads to overwhelming schedules and little time or ability to learn and grow professionally.

Science education is best when it incorporates three dimensions: science and engineering practices (SEPs), crosscutting concepts (CCCs) and disciplinary core ideas (DCIs) (National Research Council, 2012). Students must make sense of science by integrating the SEPs, CCCs and DCIs to have more authentic learning experiences (Krajcik, 2015).

New standards have been adopted in many states to reflect this changed conception of science teaching, which requires new modes of professional learning that are up to date, continuous, collaborative, practice-based and connected to local contexts (Desimone, 2009; Penuel *et al.*, 2007). Furthermore, the rural context must be considered (Howley and Howley, 2005; Oliver, 2007). Successful professional development can increase teacher and student performance (Lumpe *et al.*, 2014), but that success requires collaboration, trust and extended engagement (Blank, 2013; Edwards, 2019). Providing quality, continuous professional learning opportunities to rural teachers and studying the impact of rural contexts must be a priority.

While there are some examples of rural teachers developing robust professional networks and learning communities (Johnston *et al.*, 2018; Joubert *et al.*, 2020), this is rare (Durr *et al.*, 2020), especially when focused on specific topic areas such as science education (Barrett *et al.*, 2015). Thiele and Bogden (2022) demonstrated that rural teachers could use technology to connect with teachers outside their districts, but such collaborative groups are not widespread.

The current study introduces a new way to use the principles of lesson study (LS) by integrating technology to connect geographically isolated educators.

Lesson study

LS is an instructional inquiry model (Lewis and Hurd, 2011). The LS process involves educators collaborating around shared goals for student learning and co-creating lessons to meet those goals. The produced lesson is taught to students in the group's presence. The group then meets to discuss what was observed about student learning, the teaching process and the lesson itself. The lesson is then revised and retaught, creating an iterative experience that develops educators' knowledge and motivation for teaching, thus producing robust professional learning (Lewis and Hurd, 2011; Lewis *et al.*, 2004).

LS is consistent with the principles of effective professional development (Huang *et al.*, 2019; Lewis *et al.*, 2009). LS allows teachers to concentrate on critical elements, such as planning and reflection. They also observe someone else's lesson—a possibility often only offered during student teaching. Watching another teacher allows observers to focus on student learning and misconceptions. The LS process emphasizes revising and improving the lesson over evaluating the teacher's skills, becoming a collaborative, supportive activity among educators. Each teacher claims ownership of the created lesson and shows vulnerability by inviting others into their classroom.

Technology-mediated lesson study

LS can be complex for teachers in any school. Synchronizing schedules and being present in another's classroom is challenging (Huang *et al.*, 2020; Soto *et al.*, 2019), as is the lack of

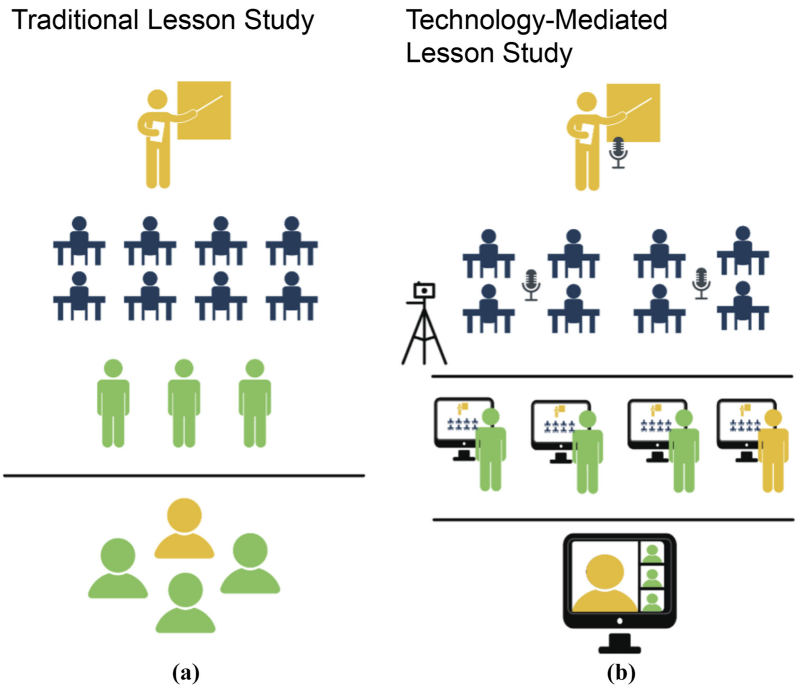
qualified facilitators familiar with LS (Cravens and Drake, 2017). All of these difficulties are even more pronounced for rural teachers. Technology-Mediated Lesson Study (TMLS) integrates technology throughout the process to enable LS in otherwise impossible locations. TMLS utilizes technology to view lessons and collaborate when not co-located (see Figure 1), allowing rural teachers to connect professionally. Participating in TMLS also teaches those involved to be new facilitators in future groups.

Other researchers have used technology to enhance LS processes by recording teachers' lessons (Huang *et al.*, 2021a, b; Lewis and Perry, 2017; Sharma and Pang, 2015), connecting geographically dispersed teachers (Huang *et al.*, 2021a, b; Joubert *et al.*, 2020; Koutsouris *et al.*, 2017; Soto *et al.*, 2019), or during remote instruction due to the COVID-19 pandemic (Calleja and Camilleri, 2020; Weaver *et al.*, 2021). TMLS goes beyond what these researchers did in creating networks of LS collaboration for teachers who cannot otherwise meet. This paper outlines the TMLS process so any educators can follow and adapt.

Methodology

Participants

Twelve rural science teachers participated in an in-person professional development on the principles of 3D science and the TMLS process. Three teachers were involved the prior year and returning participants became each group's science teacher leaders (STLs). Three groups of four were formed, each developing four high school biology lessons aligned with 3D science. Two teachers were from the same school and an additional two were in the same district. All others were the only participating teacher from their school or district. All teachers were professionally



Source(s): Authors' own work

Figure 1.
(a) In traditional lesson study, a teacher is observed by group members in the same classroom, followed by an in-person meeting, (b) In technology-mediated lesson study, the lesson is recorded, uploaded and reviewed asynchronously by group members, followed by a virtual meeting

isolated in the sense that they were separated from colleagues by geography or field of expertise. The teachers volunteered to participate in this research.

Four university faculty, a post-doctoral fellow and two graduate students with experience in science education, teaching with technology and teacher professional development facilitated workshops and observed teacher meetings.

Data sources and analysis

Multiple data sources were reviewed for examples of the teachers' experiences with each step of the TMLS process.

Swivl videos and comments. During the TMLS process, the teachers recorded their lessons using Swivls (swivl.com). Swivl is an intelligent technological robot that captures video and audio from within a classroom. The robot sits stationary in the room but can swivel the camera vertically and horizontally to track the teacher via a microphone marker worn around the neck. Additional microphones are placed around the room to capture student conversations. The videos are uploaded to the Swivl website.

Watching the videos, viewers can add time-stamped comments. For this project, we included a rubric to help teachers focus their remarks on 3D science elements within the lesson. Two research team members coded the video comments by organizing them into categories or themes based on coder consensus.

Online TMLS meetings. TMLS groups met synchronously using Zoom videoconferencing. All meetings were recorded, and the automatic transcription provided in the Zoom interface was utilized. Members of the research team participated in these meetings as silent observers.

Interviews. Semi-structured interviews were conducted with each of the twelve teacher participants before the in-person professional development and TMLS process and at the project's end. In these 20–40-min interviews, the researcher asked pre-determined questions with additional follow-up as necessary. Additionally, short interviews were conducted with one teacher after each TMLS meeting. Each interview was recorded, and the audio file was transcribed.

Focus group discussions. After completing the first and third lessons, groups of four teachers discussed the TMLS process and their perceptions of changes in their teaching in a 45-min focus group interview. Questions were asked about TMLS, how students responded to the lessons and how the teachers perceived their growth in knowledge of 3D science. These interviews were recorded and transcribed.

The technology-mediated lesson study process

The Three-Dimensional Rural Science Teachers (3D-RST) program is designed to help rural science teachers throughout a Western state form connections and build lesson plans aligned with the state's science standards. The focus of 3D-RST professional development is on implementing the principles of 3D science (see www.3DRST.byu.edu).

The following describes the seven steps in the TMLS process with specific examples and supporting data from the 3D-RST project and guidelines for implementing TMLS.

Step 1: gather a group

At the center of any LS is a group of educators coming together to improve teaching and learning. One advantage of TMLS is that the group is not restricted to co-located teachers.

A TMLS group commits to collaborating over an extended period while allowing others to observe their teaching, requiring familiarity and trust (Lantz-Andersson *et al.*, 2018). It is recommended that all teachers understand and create a shared sense of purpose within the group. This step can be conducted either in person or via technology.

Groups need someone to function as a group leader. The leader does not need to be the most familiar with the project's intended goals but should understand the TMLS process. The group leader functions as an equal group member—taking his or her turn to teach the lesson.

Step 1: 3D-RST example. Our first cohort was motivated by a change in the state science standards (Utah State Board of Education, 2021), which called for new methods to incorporate 3D science teaching. This shared goal helped unite our twelve participants from small science departments, where many were the only biology teachers. STLs were selected from the prior year's pilot. STLs led all group meetings and helped ensure all teachers were supported.

Step 1: data. The teachers valued working with others in the same professional situation. One teacher noted, "We don't have to worry about our principal doing something or that this kid was annoying. We can focus on lesson content and be far more productive than we [otherwise] could." Teachers indicated that the ability to focus on lesson planning was one of the main highlights of this project. Several also identified that doing LS in their schools is not an option. "Most of us don't have somebody in our school that teaches the same class. So doing [lesson study] run[s] into complications because we're singletons." This observation highlights one goal of this project—to provide LS to those who otherwise could not participate.

Step 1: general principles and recommendations.

(1) Those involved should be invested with a deep commitment to learning and implementing the lessons in their classrooms; voluntary participation may help.

(2) Meeting in person initially helps groups become acquainted and builds trust.

Step 2: identify TMLS focus

Unlike groups that form within a school or district—where shared objectives may already exist—the dispersed group joining in TMLS will need to establish shared goals (Lewis and Hurd, 2011). These objectives could be learning new curricula or standards or developing new technology skills. Teaching by or collaborating with knowledgeable content experts may be a valuable addition to the TMLS process (Huang *et al.*, 2021a, b). Expertise may also be found within the group members, particularly the group's teacher leader.

Step 2: 3D-RST example. During a weeklong, in-person workshop, university faculty and STLs provided professional learning for the new teachers to help them better understand and experience 3D. The teachers participated in lessons as students and reflected on their experiences. The workshop also provided a direct experience of seeing how all elements of 3D science can successfully be integrated.

Step 2: data. Teachers valued being taught by content experts, research team members and the STLs. One teacher commented, "Having these other teachers as mentors for me has been invaluable." They also appreciated having the opportunity to experience lessons as students. "It really highlighted how you can integrate [3D science concepts]." Even teachers who initially felt overwhelmed by the new material came to feel this way. "That first day was so overwhelming because there was so much information . . . I considered [leaving, but now] I feel I have a fairly strong grasp on the three dimensions."

Working together as a team and finding shared goals about teaching science were also appreciated by participants. In talking about his experience as the group leader, one STL said, "I've been looking into opportunities to . . . help teachers get better and improve, and this gave me a chance to do that . . . As time passed and [we] got to know one another, [we] saw how much [we] have in common, [and] how hard [we] want to work to help kids."

Step 2: general principles and recommendations.

(1) Professional development providers or knowledgeable content experts can provide training to support TMLS objectives.

(2) Teacher leaders should be equal members of the group who participate in all TMLS activities and lead the group meetings.

(3) Provide opportunities to experience and reflect on lessons as students.

Step 3: lesson development

After preparation and goal forming, groups co-design a lesson. This lesson can be based on a particular standard or topic that all the teachers will (or would like) to cover in their current classroom curriculum. This process can be done in person or virtually, but meeting synchronously is vital for collaboration, focusing on implementing the new standard or method emphasized by the group goals. Microteaching the lesson to a small group of supportive colleagues or volunteers allows the group to evaluate it before teaching students.

Step 3: 3D-RST example. During the summer and subsequent in-person workshops, the teacher groups developed most ideas for lessons, the science concept that would be taught, lesson activities and any student worksheets or evaluations. Research team members were present to observe and document the group processes and occasionally provide additional support.

After two days of developing a new lesson, one teacher from each group taught the lesson to a small group of other workshop attendees for practice and feedback. These microteaching experiences allowed the group to make revisions and work out the timing of lesson elements. After the microteaching, the groups updated their lesson plans to prepare to teach the lesson to their students.

Step 3: data. The teachers provided feedback on the lesson development process. They agreed that collaborating with other educators in groups helped them think in new ways. One teacher described how the group's work has improved his thinking. "It's been super helpful to feel like there are people who have ideas in [other] areas . . . It's been the group setting that has helped give me ideas."

Teachers also expressed how much they enjoyed working in groups to create lessons. "[Here we are] working together to try and make a lesson better, as opposed to focusing on who's the best teacher." Teachers also spoke about how confident they became working together. "We are very comfortable in sharing whatever our thoughts are. If I want to say something . . . I don't have any inhibitions."

Step 3: general principles and recommendations.

(1) Build on group members' strengths while ensuring the workload is evenly distributed.

(2) Provide ample time to create lessons and opportunities for microteaching.

(3) Have document-sharing capabilities.

(4) Create or provide a lesson plan template.

(5) Knowledgeable content experts can help evaluate, but the group leaders should oversee most of the evaluation.

Step 4: teach, record, watch and respond

Following lesson development, one teacher teaches the lesson to a class of students and records it. A critical principle of LS is to have other teachers observe student learning—primarily student actions or conversations that the teacher may not directly observe. Observers monitor student conversations and behaviors to evaluate the efficacy of the lesson. Because the lesson has been co-created, a commitment to teaching it as written helps the subsequent group analysis focus on the lesson's content rather than a particular teacher's

unique personality or skills. After the lesson has been recorded and shared, everyone watches, reviews and makes comments about the lesson's implementation.

Step 4: 3D-RST example. After the workshop, the first teacher in each group taught the lesson to a high school science class. Using the Swivl robot, the teacher records and uploads the video for the rest to watch. All group members commented on the video about how the lesson worked, any changes needed, how students responded and the evidence they saw of the 3D science elements.

Step 4: data. After analyzing video comments, researchers observed that comments tended to occur in four large categories, as described in Table 1. Overall themes identified in the comments indicate that while the teachers were instructed to comment about 3D elements, these only occurred about 25% of the time, despite an included rubric that focused on 3D science. Many comments instead focused on other aspects of the class experience being observed. For instance, 38% of comments were about the teaching experience. Comments focusing on student performance occurred 23% of the time, which helped the teachers identify student engagement and learning. Frequent comments about the lesson plan (38%) indicated something that should be changed or added. Therefore, most comments—even those with a different focus than 3D—helped the team prepare to discuss the lesson. Despite most comments not concentrating on 3D elements, teachers still found value in having a 3D-centric rubric: "I think [the rubric] is great; it helps keep the comments focused."

In interviews, teachers often commented on being recorded and watching themselves and others teach. One participant explained, "Because I'm at a school where I'm the only science teacher, . . .it's the first time I've been recorded and had people look at it . . . who have to teach the same content."

Step 4: general principles and recommendations.

(1) Recording, uploading and viewing videos should be easy, convenient and confidential, especially when sharing videos of classrooms across schools or districts.

(2) Comments should be focused on the lesson content; a rubric or guide may help.

Step 5: meet to discuss and revise the lesson

After viewing the video, meet via video conferencing. Meetings should focus on making changes to the lesson plan and supporting materials and evaluating how well the lesson met the overall goals for the TMLS process.

Discussions are under the teacher leader's direction. Meetings often begin with a summary by the one who taught, followed by other members' thoughts and lesson evaluation. Each TMLS group can construct the format of meetings to best suit group needs. Some groups may prefer to revise the lesson together. In contrast, others may identify required changes and make assignments outside the meeting. Nevertheless, all discussions should center on evaluating and modifying the lesson according to the TMLS group goals.

Video comment category	Example	Percentage
Teaching experience	I should have had a student model the process, but I decided to do it myself	0.38
Student performance	Students are coming up with some pretty interesting ideas already	0.23
Lesson plan	We need to add more details to the lesson plan about using the slides	0.38
3D science elements	Explaining the human activity part is a link to the DCI	0.24
Supportive comments	You did a great job with that lesson!	0.13

Note(s): Comments could include multiple categories, so fractions do not sum to 1
Source(s): Authors' own work

Table 1. Video comments categories, an example and the total fraction of comments that contained the category ($N = 650$)

Step 5: 3D-RST example. Teachers met using Zoom. Meetings tended to last between one and two hours and were conducted by the STLs. Research team members were also present but usually kept both cameras and microphones off unless addressing a specific concern or question from the teachers.

The Educators Evaluating the Quality of Instructional Products (EQuIP) rubric (NGSS Lead States, 2013) was used to evaluate lessons to help teachers focus on and evaluate 3D science elements in the lessons. By centering discussions on the EQuIP rubric, groups could better focus on 3D science principles, deeply assess how well they were incorporated and make modifications as necessary before the next teacher taught.

Step 5: data. Overall, the teachers were optimistic about meeting in their groups. One teacher said, "The team communicates well …. They've prepared and come with their thoughts." Another teacher expressed how working with the technology makes the meetings more successful, "I love that we can be on different live documents and talk each other through specific changes so that we can improve things right then."

Teachers were generally optimistic and complimentary when asked how a meeting went directly after a TMLS meeting.

> I don't think there's any doubt that every time we meet and then talk about ideas … it makes the lesson and what we are doing that much better. Without that interaction—if it were just up to me—I would teach the lesson, and I know I would have all kinds of ideas of what I could do, but I wouldn't go back and change it. But having some accountability, knowing that other people [will] teach the lesson … [makes it] better.

Step 5: general principles and recommendations.

(1) Focus on the lesson rather than the teacher.

(2) The group must be committed to collegial, supportive and constructive feedback.

(3) Find tools or resources to help evaluate the lesson, such as a rubric.

Step 6: repeat steps 4 and 5 until all group members have taught the lesson

Once the first teacher taught and the group met and amended the lesson plan, a second teacher teaches and records the revised lesson. The group then watches the video, meets and adjusts the lesson again. This process is repeated until each group member has taught and had their lesson analyzed.

Step 7: reflection and possible beginning of new TMLS cycle

LS is often a multi-year experience with numerous iterations (Fernandez, 2002). After the first lesson is complete, it is helpful if the group meets either in person or virtually to review the overall process and final product. It can be beneficial to discuss what went well with the TMLS process and what they want to improve in the next cycle. One way to gain insights into this process is to discuss with other groups who have developed different lesson materials and consider ways to improve group interactions and processes.

Step 7: 3D-RST example. After completing each TMLS cycle, the groups met in an in-person, two-day workshop to review their experiences and prepare for the next cycle. The teacher groups and research team ascertained what worked, how perceptions of 3D science changed and what was learned from working as a group. Both the research team and STLs provided additional 3D science training. The teacher groups then chose a new standard and began working on a new lesson plan. Four lessons were developed in this way during one school year.

Step 7: data. Several themes from the conversations between teacher participants and researchers about how teachers grew from participation in TMLS are discussed next.

Working together as a group. Teachers frequently expressed how well their groups work together. They appreciated the camaraderie and the lack of contention. "The cool thing is that I don't feel like we've got a bunch of pride . . .. If one of us has an idea that is so-so, but one of us comes up with something that might be better—it's not a fight."

One teacher expressed how his group responded to something that needed to be changed in the lesson by explaining:

> We all noticed the same thing in the [Swivl] video. We decided to make a fairly big change [by] taking something out. We were all focused . . . and everyone was pretty straightforward in evaluating the benefits and drawbacks . . .. We do a good job of looking at this as a collective effort . . .. We're not concerned about getting our feelings hurt . . . because it's our project. It's not just one of our babies.

Teaching improvement. Teachers frequently commented on how much they have grown as educators. One group expanded and improved a lesson already used by one group member. The teacher who had the original lesson described the changes: "This lesson is something that I've taught over the years, and this year—because of the work that we're doing together—it's by far a much better lesson, and the students have a much better experience than they've ever had in the past with me."

Another teacher explained how she could see the benefits for her students, "The hardest thing for me was the videoing and being so vulnerable. [But] if I wasn't willing to do that, I wouldn't have seen [that] these kids were so engaged in the lesson." This teacher also said that being involved in TMLS has "changed everything because it makes me more of a conscientious teacher . . .. I don't even remember the type of teacher I was before."

Learning pedagogical skills by watching each other teach was another common theme: "[What] influenced me the most [was] the videoing. Not only observing myself teach, . . . but [seeing] my colleagues do the same thing [helped me] because you pick up on things that they're doing."

Participants as knowledgeable content experts. One of the critical features of TMLS is using participants as knowledgeable content experts embedded within the groups as teacher leaders. Using STLs can lead to cohesive groups that work together well. One STL explained his role: "I help the group stay on task; help the meetings be more organized; try to help the group think more deeply about topics; and help the group come to consensus." Another teacher observed, "I've talked more with [this group] through this past year about instruction than I've probably had with anyone in the past eighteen years." Teachers also realized that collaborative groups could happen even when isolated from colleagues. "Your team doesn't have to be in your building . . .. You can create something great and support each other . . . it's okay that it's not the teacher in the room next to you."

When talking about leading a group as an STL, one spoke about how he started being heavily involved in all aspects of the process but was able to pull away as trust developed in the group:

> The first round we did, I texted these guys weekly [asking], 'What can I do to help you?' [By] the end, . . . somebody else would text, 'Hey, I got this part done. What can I do to help?' And so [everyone in the group] started reaching out.

Comments like this show that by the end of the process, all group members see themselves as equal participants; the STL is the group leader but is also seen as a peer. By the end of the process, all group members had improved their knowledge and competence to become STLs in future TMLS cycles.

Teachers also discussed how their collaboration extended beyond the official meetings by describing outside communication.

> Multiple times a week, there was some form of contact between us . . .. It [helped create] a network that I felt good reaching out to: I didn't have to wait until the meeting . . .. I could reach out to the group at any time, and that has helped even beyond the lessons.

Discussion

TMLS was created to allow isolated educators to participate in a LS professional development method. Through TMLS, teacher groups create, teach, evaluate and refine lessons. Hence, utilizing TMLS provides educators with high collaboration and trust with fellow group members. Going through even one cycle of LS with a single lesson fulfills the need for professional development to be ongoing, in that the process can average between 4 and 8 weeks. In this way, teachers develop and practice new pedagogical knowledge and are given multiple opportunities to practice and observe it in others. Teacher participants noted that this process takes time, but it is this time that has allowed them to improve.

Teachers also are provided with the opportunity to develop their content knowledge. In the 3D-RST TMLS cycles, teachers improved their understanding of 3D science instruction, which was evident even beyond the lessons created for the project. Teachers indicated they were incorporating 3D thinking and practices in lessons throughout their curriculum.

While technology is an integral part of TMLS, a minimal investment in technology is needed to form a TMLS group. The basic technology requirements include a way to record and upload lessons so others can view them, a method of document sharing and a way to meet virtually. TMLS is for groups who otherwise could not meet without using technology to connect them. For this project, hundreds of miles separated some members of the group who could still have meaningful collaborative groups that created high-quality lessons and improved teacher learning.

The steps and process of TMLS are not unique or new; in fact, they are similar to the process of technology-assisted lesson study (TALS), as described by Huang *et al.* (2019). However, TMLS is distinct from TALS in several ways. First, TALS has a primary research focus, while TMLS has a practice focus, which is evident in the composition of TMLS and TALS groups. At each meeting, TALS had two teachers, an expert facilitator, and three researchers actively engaged in the LS process. In TMLS, groups are composed entirely of teachers, with one teacher among them co-designated as a STL who acts as the facilitator.

Second, TMLS is more easily scaled and expanded. The TALS model requires many outside experts and researchers to partner with each LS team beyond the human and economic resources available to most teachers, schools, or districts. TMLS is teacher-driven, with groups of practicing teachers, making the model accessible to teachers anywhere.

Third, while we cannot speak to the underlying philosophy of the creators of TALS, TMLS was created to support building capacity in rural teachers. People are the primary goal of our work. We believe that rural teachers are the best situated to understand the needs of their students and solve the problems of practice that may exist in their classrooms. We also believe that when teachers are treated as professionals and allowed to collaborate meaningfully, they will become better educators and feel more engaged and respected. This philosophical framing is foundational to the way that we have designed TMLS.

Finally, all three of the previously stated reasons culminate in a different model for facilitating TMLS. In the pilot year, four rural teachers formed a group to create lessons and learn about the LS process. In this first year, the research team was involved in all aspects of the process by helping develop and refine the lessons and facilitating all group meetings. However, after this first year, when nine additional teachers joined, the roles of the researchers and the original teachers changed. Three original participants were designated as STLs and became equal parts group members and leaders. Thus, in the project's second

year—as described in this paper—the researchers stepped back and were not as involved in the training in three-dimensional science or leading in-person or online meetings. Instead, STLs took charge of each lesson's instruction, implementation and evaluation of 3D science elements. Unlike the teacher facilitators in TALS, STLs were equal participants in the TMLS process—helping write and teach the lessons. The research team's role became one of support and observation.

TMLS impact and usage

TMLS is designed for educators who lack opportunities to collaborate with others in similar teaching situations. Geography is not the only cause of teacher isolation. Professional isolation can happen even for educators in large or urban schools. For example, schools with large science or English departments may still have small departments for vocational or art classes. Specialized teachers also lack large cohorts. TMLS can be used and modified for educators of any discipline.

TMLS has the potential to be self-sustaining. After the year of the project described in this paper, nine teachers continued for a second year. This perpetuation indicates that this process can continue to grow beyond the confines of a research project as rural teachers reach out to other educators: teacher participants becoming knowledgeable content experts for their peers.

Limitations

One limitation of the conclusions drawn from this research is that all teacher participants did so voluntarily; they self-selected to be part of this process and were intrinsically motivated to improve their three-dimensional science teaching knowledge and skills. It is unknown how educators would respond to the TMLS process if it were required rather than voluntary.

Future directions

The 3D-RST project continues to collaborate with teachers and intends to explore more aspects of TMLS with them. Some of these areas include the personal, social and contextual elements of TMLS for rural secondary science teachers. We call on other researchers to focus on the practical needs of rural teachers in all disciplines so they can improve their practice, grow as educators, collaborate with others and minimize the challenges of rural teaching. We hope that peer observations of teaching become more common for professional growth and social interaction. We hope others will utilize TMLS for research and practice.

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