# Investigating Teacher's Technological Pedagogical Content Knowledge in a CAD-enabled Learning Environment

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## Introduction

There has been an increased emphasis on the integration of engineering design with science learning across all grades in the K-12 school curriculum. A critical aspect of this integration process is understanding teacher preparedness and their knowledge about the technology, content, and pedagogy relevant for the effective implementation of such integrated curriculum. Researchers have highlighted the perennial yet ill-defined need for preparing teachers to integrate technology in teaching and learning (Koehler, Mishra, & Yahya, 2007; Rodrigues, 2003). In fact, prior research suggests that teachers may not be prepared to integrate technologies and other scaffolds that are crucial for students' productive engagement with engineering design (Koehler, Mishra, & Yahya, 2007). Teaching technology skills isolated from the classroom context in which they need to be implemented does not help (Kenny, 2002). Thus, the need of the hour is classroom environments that provide teachers opportunities for engaging deeply and meaningfully with the technology and scaffolding the implementation of technology to support science and engineering learning. This exploratory work presents findings from a study that investigates teachers' technological pedagogical content knowledge in the context of a project-based unit using a CAD tool- Energy3D (Xie et al., 2014). It looks at ways in which teachers orchestrated their classroom instruction and interactions with the students. The research question guiding this study is- How do teachers orchestrate a project-based engineering design and science activity supported by a CAD tool?

## Method

A single subject case study approach has been used here and findings from a study conducted in one US high school classroom in the northeast has been presented. Students worked on a 50-minute, five-day long problem involving the design of a net-zero energy home i.e. a house that did not consume electricity from the grid. The class was taught by Ms. KM who had about 10 years of experience teaching science in grades 6 through 12 at the time of data collection. Ms. KM did not have any prior experience of using a computer-aided design software or science simulations. While she did not have any experience teaching engineering design, she did have a graduate degree in environmental engineering and had experience of the engineering design process through various design projects.

Data collection consisted of audio recording teacher conversations or teacher moves in the classroom. The research team transcribed and analyzed the audio recordings. Due to lack of teacher interview data, post hoc analysis of teacher beliefs and knowledge based on the enactment of instructions in the classroom was done. Mishra & Koehler's (2006) Technological Pedagogical and Content Knowledge (TPACK) framework was used to analyze and interpret the teacher moves. This was selected as the analytical framework since it enables an in-depth understanding of a teacher's technological knowledge (T), pedagogical beliefs (P), and content understanding (C). It provides a way of interpreting the dynamic interplay between these aspects of teacher readiness, paving the way for the design of effective scaffolds and resources for helping teachers overcome challenges that they might face, while facilitating students' productive engagement with engineering design and science concepts. This study focuses specifically on the intersections of technological, pedagogical and content knowledge to facilitate a deeper understanding of how these interact in the context of the engineering design process. Based on Mishra and Koehler's (2006) definition of these intersections and keeping the research context in mind, in this paper, Pedagogical Content Knowledge (PCK) is the knowledge of pedagogy that is applicable to the teaching of specific content related to efficient energy generation and use. It is operationalized as instances of the teacher using prior knowledge about solar panels or energy efficiency in order to organize instructions. Technological Content Knowledge (TCK) is the knowledge about using the CAD tool's features, analysis tools and representations for teaching content related to efficient energy generation and use. It is operationalized as instances of the teacher using the features and representations built into the CAD tool to demonstrate relationships between design variables. Technological Pedagogical Knowledge (TPK) is the knowledge about CAD tools to implement specific pedagogy. It is operationalized as instances of teacher facilitating inquiry learning and promoting systems thinking using various features of the CAD tool.

The CAD tool used for this study, Energy3D, affords students to conduct inquiry about energy efficiency and heat transfer. It provides visual feedback (e.g., graphical representation of annual energy usage and thermal energy distribution) to the students and enables them to understand relationships between various design parameters (Taleyarkhan et al., 2016). Additionally, it allows teachers to scaffold the learning process by leveraging these visual feedback mechanisms (Dasgupta & Magana, 2017).

## Findings and Discussion

In this exploratory study, we focused on describing various teacher moves used to orchestrate a project-based engineering design and science activity supported by a CAD tool. We wanted to first understand the distribution of teacher's technological, pedagogical and content knowledge throughout a 50-minute, five days long design session. In particular, we noted the intersections of these constructs to understand the interplay between these connected constructs. We found that over a period of five days, Ms. KM's conversations with the students reflected PCK 45% of the time, TCK 38% of the time and TPK 17% of the time (Figure 1).

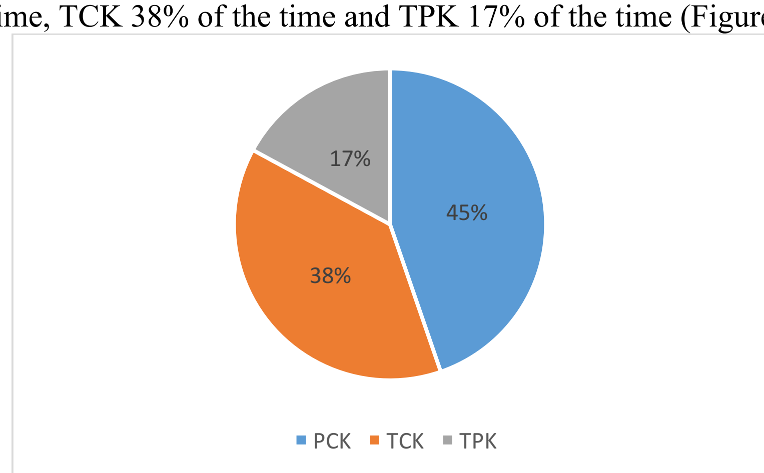


Figure 1: Ms. KM's TPACK distribution

Pedagogical Content Knowledge (PCK). Ms. KM *problematized* student learning and design decisions about making the house more energy efficient. For instance-

> KM: Oh yeah, well why don't you play around with and see what that does if you add some more [solar panels], right? And is your orientation of them good?
> Sam: Yeah.
> KM: Yeah? Okay. So play with that and see if you add a few more and see if that makes sense. Yeah your numbers came way down. You're moving in the right direction. And your house looks really nice, so keep it up Sam, you're doing great.
> Sam: Thanks.
> KM: You're welcome, I'll come back and check in a little bit.
> Sam: Okay.

In this excerpt, Ms. KM encouraged the student, Sam, to review the placement, orientation, and the number of the solar panels. She gave Sam *space to reflect* on the design decision. Although Sam claimed to have a good orientation of the panels, Ms. KM problematized the claim. She did so while making sure that Sam remained motivated. She provided positive *feedback* ("Yeah your numbers came way down. You're moving in the right direction…"). At the same time, she also made sure that Sam knew that she would come back and check on the progress ("I'll come back and check in a little bit"). In the process, she conveyed that the design process was not complete yet and there was room for further improvement thereby encouraging Sam to perform more iterations.

Ms. KM also ensured that her students had the *authority* and felt *ownership* of their work (Engle & Conant, 2002). For instance-

> KM: Hey guys, Carl and I just had a very interesting discussion about something you might want to take into consideration for your design and I asked Carl to be so kind as to share with you what he has figured out.
> Carl: So I was just in the thing and I read that I was losing a lot of energy through my window in particular. So I went to the windows and had them double paned and I was losing a lot of less energy, but that increased the cost of the windows by a lot. So I'm now over budget. So I have to figure out another way to lower the cost of that, so like making the window smaller. But you can also like decrease the energy released through your walls and your door and your roof just by clicking on it and making them well insulated you'll save a lot money on losing energy.

Here Carl found through experimentation process that there were multiple ways to reduce energy loss from the house. Ms. KM positioned Carl as the owner of this new knowledge in the classroom and gave him the authority to share this knowledge with the entire class. Carl summarized his findings and shared his design process with the class, going over the tradeoffs of his design decisions.

Technological Content Knowledge (TCK). Ms. KM used the representations embedded in the CAD tool to *demonstrate concepts* and help her students *analyze the outcome* of their design decisions. For instance, she helped Sam interpret the meaning of the annual energy usage graph that students can run to analyze how much energy the house is consuming across the year-

> KM: So that way you can see a huge drop. These red triangles are represented by that red line that first run we just did that (unclear) is up there.
> Sam: (unclear)
> KM: Right. Look at that. You're down by half now. See that?
> Sam: Yeah.

Ms. KM helped Sam interpret the energy usage graph and understand the implication of a recent design change. She also helped Sam compare the energy consumed by the current design with the energy consumed before ("…first run we just did that…"). Thus Ms. KM used technology to *quantify the iterative progress* and enable the student to *understand design implications*.

Technological Pedagogical Knowledge (TPK). Ms. KM used the CAD tool to promote *inquiry*. For instance-

> KM: So if I were to draw you a picture with my stellar artistic abilities here and this is my house and I have the heliodon here passing over the midline of the of the middle of the roof, and more solar panels over here and over here, is that, are those solar panels going to be efficient in terms of getting energy from the sun?
> Jack: No
> KM: No. What am I going to want to do? I'm going to want to rotate my house right? So that the heliodon is like that right? So you might consider the orientation of your house. Um anything else you can do to improve energy efficiency? So we've talked about sizing, making it smaller, we've talked about appropriate placement of solar panels relative to the heliodon. What else? Anything else I can do to improve energy efficiency?

Here Ms. KM probed the students regarding design variables that could improve the energy efficiency further. She provided an example or "picture" of a house with certain design characteristic to help students explore the design space. Ms. KM's use of this additional resource along with the tool's features such as the heliodon and energy generation information from solar panels likely helped her facilitate inquiry in her classroom.

Ms. KM also used the CAD tool representations to revisit the design constraints. She also helped her students make connections between multiple design parameters of the house thereby promoting *systems thinking*. For instance-

> KM: Ok so Derek mentions that he's having a hard time with the energy constraints right? There (unclear) energy used at home and we want our energy usage to be down to to zero. Has anyone found ways they've been able to improve their energy usage? What are some things you've been able to do to improve energy usage?
> Carl: Um well I've like made the house itself be like as small as small as it can be within the requirements.

> KM: Ok so uh Carl made his house smaller. So you've noticed you use less energy in the smaller house.
> Carl: Yes.
> KM: Ok so you could reduce your house size. What else might that help with? In terms instead of just energy uh besides just energy consumption?
> Brenda: Cost.
> KM: The cost. So as the size of your house goes down obviously um it also costs less. Um ok. What's something else that you guys have found that improves energy consumption or reduces energy consumption?
> Deanna: More solar panels.
> KM: How many of you guys have found that more solar panels, better or less energy consumption? Has anyone found anything specific about the placement of the solar panels? Are there better placements than other placements?

Here Ms. KM probes the students and encourages them to articulate the connection between various design parameters.

Thus, we found that Ms. KM leveraged technology to focus on the content and also implement various pedagogical moves. The combined distribution of instances of such teacher moves using technology was relatively high (i.e. TCK & TPK combined-55%) as compared to moves without using technology (i.e. PCK-45%). While prior research shows that teachers struggle to integrate technology effectively into their classrooms, we have thus demonstrated how this struggle may be alleviated using a CAD tool along with a project-based activity.

## Conclusion

In this study, we have discussed a few teacher moves using a CAD tool that may facilitate effective integration of technology in the classroom. Ms. KM demonstrated pedagogical content knowledge by problematizing students' design decisions about making the house more energy efficient and giving them opportunities to reflect on these decisions. She provided positive feedback to the students to keep them motivated, all the while ensuring that her students had the authority and ownership of their work. Ms. KM leveraged the features in the CAD tool to teach the content thereby demonstrating technological content knowledge. She used the representations embedded in the CAD tool such as annual energy analysis graph to demonstrate science concepts and help her students analyze the outcome of their design decisions. She used technology to help her students quantify the iterative progress and enable them to understand design implications. Finally, Ms. KM used the CAD tool to promote inquiry as well as systems thinking by helping her students make connections between multiple design parameters thereby evidencing technological pedagogical knowledge.

We acknowledge that this single case study does not enable us to make generalizable conclusions. However, that was the not the focus of this exploratory study. Further studies are needed to make such claims. We believe that the TPACK framework affords a holistic view on teacher practices and classroom orchestration in an engineering design context. Ultimately, this will help us develop systematic scaffolds based on naturally occurring teacher moves such as those described above, and inform teachers' professional development.

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