Talking about design: Teacher talk about design ideas with teams of middle schools during engineering design projects (Fundamental)

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Talking about design ideas: Middle school teachers' support of design ideas during interactions with teams (Fundamental)

Abstract

The ways in which teachers talk to their students greatly affects how students conceptualize and approach their learning. In order for students to authentically practice engineering design, teachers must provide their students the freedom to develop and try out their own ideas, but must still maintain support when needed. This study analyzes these competing roles by examining the ways in which teachers talk to teams of middle school students as they work on engineering design projects, addressing the research question: How do middle school teachers use their talk to scaffold students' design ideas during teacher team interactions throughout engineering design projects? This study used data from the classrooms of six teachers, two teachers each from sixth, seventh, and eighth grade who all taught in the same rural, Midwestern school district during their implementation of 3-5 week long engineering design-based STEM integration units. This study focused on interactions between the teacher and teams of three to four students. The data consisted of transcripts of all the interactions between each teacher and two target teams per classroom over the course of the unit. A content analysis was conducted using a coding scheme that was developed around different types of support of design ideas from the teacher. These types were: prompts to elicit student ideas, follow-up, critique, and directly suggesting ideas. Results indicate that teachers often used their talk as prompts to elicit student ideas to initiate interactions and gather information to formatively assess their students. These examples also provided opportunities for students to practice explaining their ideas. When students struggled with mathematics or science concepts that they needed for their design, the teachers often used follow-up questions to prompt further thinking and challenge misconceptions that the students held. When students struggled with their design ideas or with implementing their ideas, teacher often directly suggested ideas rather than using the other types of talk to direct their thinking. By directly suggesting ideas, the teachers often took away opportunities for students to learn from their struggle and from the failure of their ideas.

Intro and Literature

The ways in which teachers talk to their students greatly affects how students conceptualize and approach their learning [1]–[3]. In order for students to authentically practice engineering design, teachers must provide their students the freedom to develop and try out their own ideas and learn from the failure of their ideas [4], [5]. On the other hand, teachers often use their talk to maintain their control in the classroom and guide students towards expedient solutions [6], [7]. This study analyzes these competing roles by examining the ways in which teachers talk to teams of middle school students as they work on engineering design projects, addressing the research question: How do middle school teachers use their talk to scaffold students' design ideas during teacher team interactions throughout engineering design projects?

The ways in which language are used and the ways in which teachers talk to their students varies across disciplines and contexts. For example, Bower [8] found that even individual teachers change their talk across disciplines in a study of teachers who taught both Physics and Alegbra. Many other researchers have examined effective ways for teachers to talk to their students in a range of disciplines (e.g., [9], [10]).

However, the best ways to talk to students about engineering design is not well understood. This is especially true for younger students. The ideas to teach in engineering design, although built on science and mathematics concepts, are unique. These challenges include teaching students to deal with ill-structured problems, balance criteria and constraints, brainstorm multiple solutions, and use evidence to back up their ideas [11]. There has been some research with teacher talk for more advanced students, such as in senior undergraduate level mechanical engineering projects (e.g. [12]–[14]), that can inform teachers' practice at younger levels. However, younger students, such as the middle school level that is the focus of this study, have unique needs in the ways their teachers talk to them [15]. This study aims to better understand these needs by examining the ways in which six different middle school level teachers talk to their students about their design ideas while the students are actively working in teams on engineering design projects.

Theoretical Framework

In this study, students were engaging in one of their first structured engineering design experiences, which is a challenging task [9]. In order to learn things that are outside of their abilities, students can be supported by a more knowledgeable other [13], [14]. In the middle school classrooms, the teacher acts as the more knowledgeable other, scaffolding students to support their learning about engineering design, in this case. Teachers use many different pedagogies to build this scaffolding, including the curriculum they use, the structure of their class, and how they use their talk. This study focuses on one aspect of scaffolding, teacher talk. Narrowing further, this study focuses on how teachers scaffold their students' talk during interactions with small teams of students, providing potential opportunities for teachers to tailor their talk to the specific needs of the students in the team.

Context

This study was conducted using data from the classrooms of six classroom teachers, Ms. Lane, Ms. Allen, Mr. Parker, Ms. Stone, Mr. Reed, and Mr. Smith, all pseudonyms, during their implementation of 3-5 week-long engineering design-based STEM integration units. Two each of these teachers taught sixth, seventh, and eighth grade. These teachers all taught in the same rural, midwestern school district. Demographic information is displayed in

Table *1*.

Table 1.

Demographic information of school district

Demographic	Percentage
Race/Ethnicity	
White	94
Black	1
Hispanic or Latino (of any race)	4
Two or more races	1
Students with a disability	11.8
Language other than English spoken at home	5.4
Free or reduced-price lunch eligible	49.2

Each grade level implemented a different engineering design-based STEM integration unit developed by the EngrTEAMS project. Descriptions of the context for each unit are included in Figure 1. Each grade level implemented a different unit, which each had different contexts, but similar structures. Prior to the implementation of the engineering design based STEM integration units in their classrooms, the teachers participated in a week long professional development program conducted by the authors. The focus of the professional development was on engineering and STEM integration with the specific goal of supporting the teachers through their implementations of the specific unit they were working with. Specific topics included working through each of the activities in the unit for their grade level, practice with rubrics to assess engineering notebooks, and STEM integration in general. Specifics about language or talk were not included in the professional development.

Science Content Focus/Grade Level of implementation	Description of the problem that students are presented with in the unit
Light and Waves 6th grade	Laser Secure, Inc., designs security systems to protect valuable assets, and the company is seeking help from students to design a laser security system to protect the artifacts in a traveling museum exhibit. Students investigate properties of light, including reflection, refraction, absorption, and transmission. Their solutions must protect the artifacts by having an intruder cross the laser light at least three times between entering the door and encountering the artifact using mirrors, lenses, and a laser pointer as their materials.
Heat transfer	A team that works with small businesses in Ecuador has discovered that some of the Ecuadorian fishermen need help.

7th grade	Once the fishermen return to the fish markets, they need a small cooker container to cook the fish in so they can be sold. Students design this cooker container. Before designing solutions, students learn about the science of heat transfer, including conduction, convection, and radiation. They also analyze data by creating temperature vs. time graphs and comparing different line graphs qualitatively.
Genetics 8th grade	University of Minnesota's Agricultural Department needs to determine if a new barrier effectively reduces cross-contamination of nonGMO corn fields from genetically modified organism (GMO) corn fields. Students learn about GMOs and mathematical and scientific concepts related to genetics and heredity, and use what they know to develop a strategy to test for cross-contamination once this newly proposed barrier is installed. Designs for the unit are evaluated to assess the extent to which the experimental designs meet the specifications of the client and reliably test for cross-contamination.

Figure 1. Descriptions of the context of each engineering-design based STEM integration unit.

Methods

This study utilized naturalistic inquiry to examine how teachers talked to teams of three or four students about their design ideas as they were actively working on engineering design projects in their teams. Naturalistic allowed us to analysis the teacher's talk in their natural manners with minimal interruptions from the research team [16].

Data, in the form of videos, field notes, and pictures, were collected over the entirety of the implementations of the units in each class. Within this larger data set, this study focuses on only those times when teachers were interacting directly with small teams of students. The content of these interactions encompassed many different components; this study focuses on all talk related to students' design ideas. Each unit lasted between 3-5 weeks in each classroom. Over the course of this time, there was a total of 403 interactions between teachers and teams of students. Table 2 displays the number and length of time of teacher-team interactions for each teacher.

Table 2.

Summary of teacher-team interactions.

Teacher	Team #	Number of interactions	Average length of interactions (min:sec)	Total number of class periods included in analysis
Ms. Lane	1	31	0:24	9
	2	39	0:25	
Ms. Allen	1	35	0:36	9
	2	32	0:38	
Mr. Parker	1	40	0:28	11
	2	40	0:16	
Ms. Stone	1	21	0:26	9
	2	43	0:35	
Mr. Reed	1	28	1:08	8
	2	33	0:58	
Mr. Smith	1	31	0:38	8
	2	30	0:43	
	Total	403	0:35	

To analyze the teacher talk, a content analysis was conducted focused on different types of support of design ideas from the teacher. The data analysis consisted of several rounds of coding [17]. First, an open coding process was used as the data was being transcribed to keep notes about potential codes to use. These notes were developed into an initial coding scheme. These initial codes were compared to the data to look for examples in the data that were missing or not accounted for in the coding scheme. When these missing areas were found, the codes were adapted to better fit the data. Finally, the codes were named and descriptions were written, along with a final comparison with the data. Nvivo 12 was used to code all the data and more closely examine themes across the data. The finalized coding scheme consisted of four categories: prompts to elicit student ideas, followup, critique, and directly suggesting ideas. Descriptions of each code are included in Figure 2 and examples of each are included in the results section.

Code	Description
Prompts to elicit student ideas	Teacher asks about students' ideas or restates students' ideas without suggesting changes so they can actively listen to students' ideas.
Follow-up	Teacher asks follow-up questions for students to consider or points to follow-up ideas to consider without giving ideas directly.
Critique	Teacher critiques specific aspects of students' ideas or the students' design, but without giving suggestions for improvement. Critique can be either positive or negative.
Directly suggesting ideas	Teacher directly suggests ideas to the students.

Figure 2. Descriptions of each code used in the analysis process.

Results

This section will present examples of each of the four types of teacher talk coded in the data, prompts to elicit student ideas, followup, critique, and directly suggesting ideas. **Error! Reference source not found.** displays the total number of words spoken by each teacher that fell into each code.

Teacher	Number of words spoken for each code throughout all teacher-team interactions			
	Prompts to elicit student ideas	Follow-up	Critique	Directly suggesting ideas
Ms. Lane	238	116	90	374
Mr. Reed	602	938	443	389
Mr. Smith	312	381	325	132
Ms. Allen	537	363	379	104
Mr. Parker	662	349	192	442
Ms. Stone	312	168	91	390
Total	2663	2315	1520	1831

Figure 3. Number of words spoken for each teacher for each code throughout all teacher-team interactions.

Prompts to elicit student ideas

The teachers all used a large portion of their talk on *prompts to elicit student ideas*, as shown in Figure 3. Examples of this code were often dominated by student talk, with the teacher primarily listening to their ideas and only interjecting with small comments. Therefore, the number of words spoken by the teacher displayed in Figure 3 underrepresent the amount of time the teachers spent on this code.

Often, examples of prompts of elicit student ideas consisted of short phrases that the teachers used to better understand the students' ideas. For example, Ms. Lane asked "What do you mean?" and "So what is this?" when students were working on their plans. In other examples, when his students were testing their ideas, Mr. Smith asked, "What's your solution?", when Ms. Allen was trying to understand her students' plan for their redesign, she asked "So this is a flat mirror [drawn on the plan]?", and Mr. Smith said "Just tell me your solution, if you had to give the elevator pitch, you have 15 seconds here." Although short, phrases such as these gave students opportunities to explain their ideas and to be responsible for explaining those ideas. They also helped students direct their responses so that they were better able to focus on smaller pieces of the larger engineering challenge.

Many of the instances of this code also served to prompt the students to think about their ideas in more depth or to explain their ideas more. For example, when students were writing the pros and cons of their different ideas in their notebooks, Mr. Reed told a team, "So, what do you mean it has the best results?", asking them to expand further on their thoughts and justify their ideas more. As his were later listing the pros and cons of their solution, Mr. Smith said "So what works? Focus on the positive. What was good about your solution?"

Many of the examples in this code group also served to prompt students to not only explain their design ideas, but also the mathematics or science concepts behind those ideas and how they related to their design ideas. For example, in the laser security system unit, the science concepts included learning about and being able to measure angles of reflection and refraction. When she was talking to her students about their plan for their laser security system, Ms. Lane asked,

Ms. Lane: Where did it [the laser light] go?
Student: It went right here [points to place on plan].
Ms. Lane: And where did you think it was going to go?

In this example, she is asking her students to think about the understanding of the angles and where the light would travel and asking them to think about how that applies to their plan as they are drawing out their ideas about where the light will travel. In another example, Ms. Stone asked:

Ms. Stone:	Can I hear a little bit about your bottom and your top [of your cooker container]? and your sides? […] So I know on the bottom you had said you're going…
Student:	Use a copper frame
Ms. Stone:	OK.
Student:	It's a good conductor, so we thought it'd draw some heat to the fish. Maybe not, but
Ms. Stone:	Yeah.
Student:	So do you just want me to read our justification?
Ms. Stone:	Sure, yeah. That would be perfect.
Student:	[reading out of his notebook] This design uses all forms of heat transfer. It uses holes at the top to incorporate convection, aluminum is used to reflect radiation, and then the copper support is used to draw heat to the fish incorporating conduction. Also, after seeing other, after seeing other designs, it is relatively cheap since we're mainly going off of 3 materials.

In this example, the teacher created an opportunity for students to explain their ideas, and they did so using several concepts from the unit. She used her talk to support their explanation without critiquing it or providing advice.

Follow-up

It was also common for teachers to use their talk to follow-up on students' design ideas, as shown in Figure *3*. These examples consisted of any instances in which the teacher asked follow-up questions or prompted students to think further about their ideas, without the teacher critiquing their ideas or giving direct advice about how to change their design. Often, examples of followup consisted of the teachers asking questions to prompt further thinking. For example, when her students were starting on their redesign, Ms. Lane asked "So you want to take out a mirror? Why do you want to do that?" In another example, when his students were brainstorming ideas, Mr. Reed asked a team "So what do you think is most reliable? How much is it going to cost? How much time is it going to take?" When Mr. Smith's students were working on their plan, he said "Ok, so if you want to plant off season, fine. There's some serious consequences to planting off season. What would the serious consequences of planting off season be?" These questions all served to help students think about different areas of the design and to get them to expand their ideas past what they had already considered.

Critique

Although less common for most of the teachers, examples of the teachers critiquing their students' ideas were important parts of their interactions. Examples of critique included both positive and negative critiques.

Many examples of positive critiques were short. For example, Ms. Lane told her students "It's looking good guys", Mr. Smith said "A thumbs up. I like it." and to another team "Ok, I like the design idea", and Ms. Stone said "It looks good, it looks…you have the right ideas, there's some good things here". These examples gave students positive feedback about their ideas and may have kept them motivated to continue to work.

The teachers also used critique to help students understand the pros and cons of their competing ideas and break down these ideas. For example, when a team was deciding between several different ideas for a way to keep the pollen from the fields separated, Mr. Reed said "Your artificial barrier's probably the most reliable." Other times, the critique was not as direct, such as when a team was working on their initial plan, Mr. Smith's student said:

Student:	OK, we've got, we put up natural barriers, like trees and hills, and we plant off season so there's no, we don't run into the GMO crops. and then we take a high sample amount, so we get a lot of samples. and then we use genetic testing.
Mr. Smith:	Well, I am glad you are a millionaire, because that sounds like a lot of money.

In this example, Mr. Smith pointed out that their solution idea would have a high cost and implied that they might need to rethink parts of their solution. In another example, as Ms. Allen's students were making their plan, she said:

Ms. Allen:	OK, but here's, here's what I want to ask you about. So if it comes through this lens, concave or convex, whichever one you put there. And we know that the angle that it's going to enter is not going to be the same as it leaves. So you've got the reflection and the refraction, but then that refraction angle is going to be way different. They're not going to travel in the same direction, are they? So it might be like way over here somewhere, depending on where it hits on that lens.
Student:	Well then I could move this here and put it here.

In these examples, the teachers asked about a certain point in the students' designs. Their talk pointed to places that the students should focus on or areas of improvement in their designs. By phrasing their feedback in the ways that they did, the teachers left the design ideas in the hands of the students. They did not take over the ideas or point to specific changes the students should make, instead leaving the power in the hands of the students.

Directly suggesting ideas

Sometimes, the teacher took control of the design ideas and directly suggested ideas to the students about what they should do. For example, when students were working on their plan and were struggling to represent their ideas on their paper plan, Ms. Lane said to her students:

> So what I would do is, you're going to put this one [places protractor on plan]. I would just draw like a little line [uses protractor as a straight edge to draw a line] and just say convex lens. And then from there I would draw another line perpendicular. I would go ahead and draw my dotted line.

In another example, when his students are working on their plan for their cooker container, Mr. Parker said to a team:

> wood might work well because it would trap the heat already in the container, right? It wouldn't be able to get out quickly. So, wood, those types of materials would work well as insulators. […] [f white felt is on the bottom] I don't think it's going to conduct heat very well up to the fish. So, you might…so something that's a good conductor for the bottom of the container.

In each of these examples, the teachers took the control of the ideas away from the students by giving a direct suggestion of what they should do, taking away opportunities for students to learn from the process of carrying their ideas through testing, evaluation, and redesign. On the other hand, these interventions may have helped the students be able to fully realize an idea and to be able to better apply the mathematics and science concepts that they were learning in conjunction with the engineering design process.

Discussion and Implications

Results of this study indicate that teachers often used their talk as prompts to elicit student ideas about their engineering designs. These prompts served to initiate interactions and to help the teacher gather information to formatively assess their students. These examples also provided opportunities for students to practice explaining their ideas, which is an important part of engineering communication [17]. These results imply that students at this level, sixth, seventh, and eighth grade, are capable of explaining their ideas to their teachers and backing up those ideas with varying levels of evidence. However, they sometimes needed further follow-up prompts from their teachers in order to think more deeply about their ideas. This is important for teaching because it implies that middle school teachers should provide opportunities during engineering design challenges for the students to have to explain their ideas so that they get further practice with defending their ideas with evidence [18]. In science education, research has shown that asking questions that develop conceptual understanding and asking students to make their meanings clear are important factors in eliciting students thinking [19]. The findings of this study suggest that the types of teacher interactions in engineering design settings identified as prompts to elicit student design ideas and follow-up mirror the types of interactions identified by van Zee et al. [19] for science education. The teacher-team interactions identified as follow-up often elicited talk about the science and mathematics concepts that the students were learning in conjunction with the engineering learning objectives. By having these conversations, teachers were able to formatively assess their students and take further steps if needed to overcome misconceptions or probe further about concepts. When students struggled with mathematics or science concepts that they needed for their design, the teachers often used follow-up questions to prompt further thinking and challenge misconceptions that the students held. Often, the teachers countered ideas that they thought were problematic with critique without suggesting how to fix the problems. These examples allowed the students to continue to think through their ideas and to maintain control of their projects, while still providing feedback for improvement. Although the students in this study often thought about changes to their design ideas based on these critique, such as in the example from Ms. Allen's class, sometimes the students continued to be unable to balance the many components of the design project, showing that they still needed some teacher scaffolding to support their work. When students struggled with their design ideas or with implementing their ideas, teacher often directly suggested ideas rather than using the other types of talk to direct their thinking. By directly suggesting ideas, the teachers often took away opportunities for students to learn from their struggle and from the failure of their ideas [20].

Conclusions

This study examined the interactions between teachers and teams of middle school students during their engagement in engineering design projects, looking specifically at conversations about design ideas. Four levels of teacher interactions were found: *prompts to elicit student ideas, follow-up, critique,* and *directly suggesting ideas.* Although each type of interaction served several different purposes, in general, *prompts to elicit student ideas* and *follow-up* allowed students to practice explaining their ideas and gave teachers opportunities to formatively assess their students. During these interactions, the students and teachers had high quality conversations about their ideas, demonstrating that middle school students are very able to explain and back up their ideas with teacher prompting and support. *Critiques* gave teachers opportunities to ask their students to think more deeply about their design ideas and about the mathematics and science concepts related to their ideas. These critiques aimed to push students to think more deeply about their ideas and to consider other aspects of the problem and solution. Often, by *directly suggesting ideas,* teachers took away opportunities for their students to learn from their struggle and from the failure of their ideas. On the other hand, by directly suggesting ideas, the teachers may have added in needed support that allowed the students to continue with their ideas and follow through with their ideas to a complete solution.

These different levels of support have important implications for teaching and learning. The teachers in this study were new to engineering design; this was their first experience teaching it. Therefore, these results show that teachers new to engineering design were able to engage their students in high quality conversations and develop questions and critiques about their ideas to push students forward. On the other hand, it also demonstrated that the teachers may have given their students too many direct ideas and did not value the importance of learning from the process of following through with their ideas. More research is necessary to understand these implications more in depth. Future work in this area will include a more comprehensive analysis of all the talk between the teachers and students during their interactions in engineering design, not just their talk that is specifically about their design ideas. This would allow a more holistic view of how the teachers support their students during the entirety of an engineering design project and how they relate other aspects of engineering outside of design. Additionally, future work could address the connections between different levels of teacher support and students learning as well as changes in how teachers use different levels of support as they gain more experience teaching engineering design.

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References

[1] N. M. Webb, K. M. Nemer, and M. Ing, “Small group reflections: Parallels between teacher discourse and student behavior in peer-directed groups,” *J. Learn. Sci.*, vol. 15, no. 1, pp. 63–119, 2009, doi: https://doi.org/10.1207/s15327809jls1501_8.

[2] R. S. Newman, “How self-regulated learners cope with academic difficulty: The role of adaptive help seeking,” *Theory Pract.*, vol. 41, no. 2, pp. 132–138, 2002, doi: 10.1207/s15430421tip4102.

[3] T. G. Plax, P. Kearney, J. C. McCroskey, and V. P. Richmond, “Power in the classroom vi: Verbal control strategies, nonverbal immediacy and affective learning,” *Commun. Educ.*, vol. 35, no. 1, pp. 43–55, 1986, doi: 10.1080/03634528609388318.

[4] A. V Maltese, A. Simpson, and A. Anderson, “Failing to learn: The impact of failures during making activities,” *Think. Ski. Creat.*, vol. 30, pp. 116–124, 2018, doi: 10.1016/j.tsc.2018.01.003.

[5] H. Petroski, *Success through failure: The paradox of design*. Princeton, NJ: Princeton University Press, 2006.

[6] D. S. Pimentel and K. L. McNeill, “Conducting talk in secondary science classrooms: Investigating instructional moves and teachers’ beliefs,” *Sci. Educ.*, vol. 97, no. 3, pp. 367–394, 2013, doi: 10.1002/sce.21061.

[7] R. E. Bleicher, K. G. Tobin, and C. J. McRobbie, “Opportunities to talk science in a high school chemistry classroom,” *Res. Sci. Educ.*, vol. 33, no. 3, pp. 319–339, 2003, doi: 10.1023/A:1025480311414.

[8] M. L. W. Bower, “The mathematics talk of a secondary school teacher of mathematics and Physics,” in Building connections: Theory research and practice (Proceedings of the twenty-eighth annual conference of the Mathematics Education Research Group of Australasia) (Vol. 1), 2005, pp. 161–168.

[9] E. Csomay, “A corpus-based look at linguistic variation in classroom interaction: Teacher talk versus student talk in American University classes,” *J. English Acad. Purp.*, vol. 6, no. 4, pp. 336–355, 2007, doi: 10.1016/j.jeap.2007.09.004.

[10] R. Tytler and G. Aranda, “Expert teachers’ discursive moves in science classroom interactive talk,” *Int. J. Sci. Math. Educ.*, vol. 13, no. 2, pp. 425–446, 2015, doi: 10.1007/s10763-015-9617-6.

[11] D. P. Crismond and R. S. Adams, “The informed design teaching and learning matrix,” *J. Eng. Educ.*, vol. 101, no. 4, pp. 738–797, 2012, doi: 10.1002/j.2168-9830.2012.tb01127.x.

[12] J. Ferriera, H. Christiaans, and R. Almendra, “Design grammar - A visual tool for analyzing teacher and student interaction,” in *Analyzing Design Review Conversations*, R. S. Adams and J. A. Siddiqui, Eds. West Lafayette, IN: Purdue University Press, 2015, pp. 307–336.

[13] C. Groen, M. C. Paretti, and L. McNair, “Learning from expert/student dialogue to enhance engineering design education,” in *Analyzing Design Review Conversations*, R. S. Adams and J. A. Siddiqui, Eds. West Lafayette, IN: Purdue University Press, 2015, pp. 197–216.

[14] M. Lande and J. Oplinger, “Disciplinary discourse in design reviews: Industrial design and mechanical engineering courses,” in *DTRS 10: Design Thinking Research Symposium*, 2014, pp. 1–22.

[15] T. G. Ganesh and C. G. Schnittka, “Engineering education in the middle grades,” in *Engineering in pre-college settings: Synthesizing research, policy, and practices*, Ş. Purzer, J. Strobel, and M. E. Cardella, Eds. West Lafayette, IN: Purdue University Press, 2014, pp. 89–115.

[16] Y. S. Lincoln and E. G. Guba, *Naturalistic inquiry*. Newbury Park, CA: SAGE Publications Inc., 1985.

[17] J. Saldaña, *The Coding Manual for Qualitative Researchers*, 3rd ed. Los Angeles, CA: SAGE, 2016.