PATHWiSE: An Authoring Tool to Support Teachers to Create Robot-Supported Social Learning Experiences During Homework

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Educational technologies can provide students with adaptive feedback and guidance, but these systems lack personal interactions that make social and cultural connections to the student's own classroom and prior experiences. Social or companion robots have a high capacity for these types of interactions, but typically require advanced levels of expertise to program. In this study, we examined teachers use of an authoring tool to enable them to leverage their classroom-based expertise to design robot-assisted homework assignments, and explore how seeing a robot enact their designs influences their work. We found that the tool enabled the teachers to create novel social interactions for homework activities that were similar to their classroom interaction patterns. These interaction designs evolved over time and were shaped by the teacher's emerging mental model of the social robot, their concept of the students' perspective of these interactions, and a shift towards informal classroom-like interaction paradigms, thus transforming their view of what they can achieve with homework. We discuss how these findings demonstrate how the context of the activity can influence initial mental models of social activities and suggest practical guidance on designing authoring tools to best facilitate the creation of computer or robot supported social activities, such as homework.

CCS Concepts: • **Human-centered computing** → *User centered design*; **Collaborative and social computing**; *Human computer interaction (HCI).*

Additional Key Words and Phrases: social robots; educational robots; authoring tools; mental models

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1 INTRODUCTION

The integration of robots into everyday life, including in workplaces, retail, homes and classrooms, is broadening and people are likely to interact with robots at an increasing rate [4, 7, 25]. Research and design of human-robot interactions (HRI) in these applied areas has grown to build our understanding of how humans can effectively communicate, collaborate, find companionship, act socially, and learn with robots. However, programming these robots, including designing social human-robot interactions, remains technically challenging. This challenge limits *who* can integrate robots into these spaces. Education is one such area where well-designed interactions with robots can provide support systems that promote socially and intellectually meaningful

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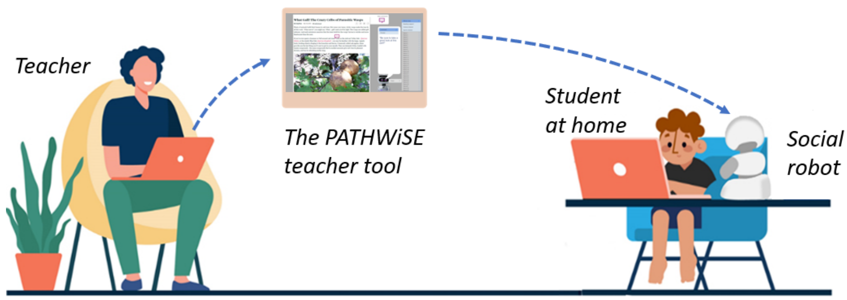

Fig. 1. The PATHWiSE system architecture, including teacher authoring tool to create student-robot homework interactions (left and center) and students completing homework with a social robot (right). © Bilge Mutlu, used with permission

learning experiences for students. However, teachers are experts in curriculum development and educational practice, but are typically novices in programming, which makes it challenging for them to implement technologies such as social robots into their classrooms or create their own custom robot-assisted lessons. Therefore, there is a growing need for authoring tools that can guide novice programmers, such as teachers, in creating human-robot interactions that allow them to apply their pedagogical expertise and knowledge of their students' learning needs.

Creating learning interactions with a social robot can be particularly helpful to provide critical social interactions during learning that foster deeper understanding through the co-construction of knowledge [47]. These types of socially rich interactions are typically provided by teachers through *guidance* to students, including giving small cues to what students might notice about their learning, restating key points in what others are explaining, or asking students questions to explain their reasoning. However, some activities, particularly homework, are often done in isolation where teachers and families can struggle to support students, making it difficult for the student to receive adequate social guidance and interaction during these activities [19]. This lack of social interaction or guidance during homework can lead to differing quality of assignment completion between work a student does in class and at home, which some teachers explain has led to a reduction or avoidance of assigning homework [27]. While robots might be exceptionally useful in providing socially rich guidance during homework, teachers are rarely adept at programming student-robot interactions that would allow them to customize the experience to the needs of *their* students.

To address these issues, we have begun a project to co-design *PATHWiSE, the Personalized Authoring Tool for HomeWork in Science Education.* PATHWiSE is an authoring tool for middle school science teachers to easily create student-robot interactions to provide rich personal and socially interactive guidance to students when working away from the teacher. Rather than creating a new alternative online teacher tool for homework creation, as these are commonly available, **our goal is to design a tool that *empowers teachers* to create unique social learning experiences with a robot** that provide meaningful connections to the material and support deeper learning. In our prior work, we have built and tested an in-home reading companion robot system for children [42–45]. The PATHWiSE system will allow teachers to *annotate* homework with custom comments, prompts, questions, and non-verbal emotional expressions that can be delivered by the robot during homework. These student-robot interactions will allow teachers to extend in-class guidance to support the child's learning at home. In this study, we co-designed science homework activities with science teachers using a prototype of the PATHWiSE authoring tool. Our goal is to: examine the process and perspectives of teachers creating socially interactive homework activities with the tool, explore how their use of the tool and perception of the robot shapes and is shaped by their approach to homework design, and identify ways to improve the design of authoring tools for novice programmers in creating computer supported social activities in education.

In this study our goal is to contribute to existing work in these areas through; describing design principles for teacher authoring tools, providing insights into potential roles of social robots based on teacher perceptions, demonstrating changing perceptions and mental models of teachers as they experience designing lessons for social robots, and demonstrating participatory research methods involving teachers in the design of social robots. Through the use of participatory design, the study also provides design principles for the robot itself grounded on what teachers consider most important, rather than solely building tools around technical capabilities.

2 RELATED WORK

To achieve these goals, we rely on prior work in the learning sciences on socially situated learning and teaching practices; work in human-robot interaction (HRI) on the application of social robots to support learning and mental models for HRI; and work in computer supported collaborative work (CSCW) and learning (CSCL) on social and collaborative educational technologies, and authoring tools for these technologies.

2.1 Socially Situated Learning and Personal Guidance

Our motivation for co-designing an authoring tool for science teachers to create student-robot homework interactions is steeped in sociocultural learning theory. A student's acquisition and integration of domain knowledge is built upon more than practicing skills and retaining facts – it is a culturally embedded and socially meditated process constructed from contextual experiences and social interactions during learning. [47, 59]. Reasoning is facilitated by exchanging viewpoints and ideas with others, is dynamic and relational, and is mediated by prior experiences and the anticipation of future social experiences. [5]. In the classroom, students benefit from *socially mediated* interactions to co-create knowledge with teachers and peers [20] where teachers responsively attend to student questions and misconceptions, prompt verbal reflections on learning and otherwise engage with students in relatable and social ways [37, 62]. In this way, teachers provide *guidance* through meaningful dialogue that emphasizes making connections to students' personal experiences and existing knowledge that build lasting and deep knowledge [8, 37].

Homework is one curricular tool teachers use to positively influence student academic achievements and can be particularly effective when connected to classwork and tailored to students' individual needs [19, 55]. During science homework, particularly in the modern era of Next Generation Science Standards (NGSS; [50]), science learning activities are complex and challenging. Thus, these learning activities, such as writing opinions on new topics, discussing ideas about readings and videos, and explaining science concepts in their own words, can require substantial guidance and social interaction to be effective [32]. While many teachers are aware of the need for social guidance in the classroom, teachers struggle to provide such guidance for homework, particularly in science, technology, engineering, and mathematics content [19, 32], leaving students to complete complex work during isolated activity. This lack of guidance contributes to inconsistencies between the quality of work done in class and work done at home, which in turn has led to a reduction or avoidance of assigning homework [28]. Thus, homework represents an area in education that can be vastly improved with the addition of socially rich learning supports.

2.2 Social Robots for Homework

Social robots represent an emerging technology that can maximally afford adding social experiences to learning activities. These systems are becoming more affordable for in-home and classroom use and have the potential to transform isolated activities, such as homework, into socially interactive experiences. Like other computerized learning systems, robots are capable of personalizing lessons for students to supplement homework with feedback. **What sets social robots apart is that they promote higher levels of social engagement when compared to online learning or with virtual agents presented on computers** [7]. This heightened social interaction between students and robots occurs as humans readily apply social rules and norms to interpret the actions of a physically present robot through a tendency for anthropomorphism, ascribing human traits to nonhuman entities [12, 23, 34, 49]. In our prior work, we have demonstrated the high level of social interaction that children have with a learning companion robot and how these interactions during shared activities promote learning and interest [43, 44]. The skills of social robots vary greatly from being command-based to full conversational interactions. This study focuses on how teachers would imagine what types of interaction the robot may have with the children; therefore, we did not define any technical limitations. In fact, their desire for context-related responses exceeded what we had originally imagined necessary but provided crucial insights. This type of learning companion robot may be quite effective when it can provide the kind of social and personal guidance teachers would provide for their students in the classroom, particularly if the teacher can integrate their own expertise and experience of their students' interests and preferences. Teachers and their students would therefore benefit from authoring tools to augment homework assignments with teacher guidance delivered via learning companion robot at home. These tools must be designed to utilize the teacher's pedagogical expertise while also accounting for a lack of expertise in computer programming and robotics. Currently neither the tools nor the theoretical guidance exist for teachers to design their own robot-assisted social or collaborative activities.

2.3 Authoring Tools

Typically, *authoring tools*, software that helps users create digital content, are designed to be efficient and easy to use by reducing the time, effort, and technical skill needed to create content [3, 52]. For teachers, authoring tools can support implementing research-based learning design principles and practices with technology [15]. Prior work has demonstrated effective methods of creating efficient and effective authoring tools for teachers, including co-designing the tools with teachers [31]; providing methods of adapting existing materials rather than creating new content [1]; and building a user interface that is structured around curricular and pedagogical goals [40]. Developing an authoring tool to augment homework with a social robot, is a novel challenge where creating robot interactions must include curricular and social components [51]. In short, an effective teacher tool should be co-designed with teachers, use a simple design, and integrate into existing workflows.

Existing authoring tools for social robotics often use menu options or visual programming to facilitate designing robot interactions in healthcare [9], theatre [17], service applications [21] and verification of appropriate social behavior [53]. However, these tools often focus on the flow of the robot actions, rather than integrating within existing activities, such as homework, and include numerous interaction dimensions for the user to manage [33]. Many robots, such as the NAO robot and IROBI come with their own authoring tools (*c.f.* [26]) that involve managing dialogue, motor control, and turn taking with a node-link or timeline style editor. These systems are effective and complex because they are comprehensive, and not specifically tailored to support designing robot interactions during learning activities. Other custom authoring tools, such as RoboStudio, allow interaction design by providing users with a State Navigation Window to manage the flow of robot actions as states that can be populated from an icon-based editor window with pre-made archetypal interaction options [21]. This approach allows designing interactions specifically related to the application area, in this case service applications, but still includes a broad array of options, settings, menus and windows for the user to manage. One authoring tool designed for educational contexts helps teachers create lessons in one window of a user interface, then segment those lessons in another, and finally add details of robot behaviors for the interaction in a third window [18]. Students were generally positive about this approach based on a survey, but teachers were not included in the design nor was their experience evaluated in the study. Our work with teachers indicates they need a simple interface to design homework interactions, as the time-cost for creating content must be quite low [28]. We believe the high number of inputs in most currently available authoring tools may not be compatible with typical teacher flows, and integrating the interaction flow more closely with the lesson materials may be more efficient [2].

2.4 HRI and mental models

A well-designed authoring tool should also support content creators in using best practices in adapting technologies into their application area. In this case, an authoring tool for social robots should help the user anticipate the social and technical affordances of the robot and how the robot's actions will be perceived. Research on human-robot interaction suggests humans create a mental model of robots they engage with that describes their expectations about the robot's behavior and function [48, 61]. Prior work has shown that mental models of robots are informed by shape and function of the robot and people's prior experiences with and without a robot [38, 57] that can inform a perception of the role and identity of the robot [22]. These mental models influence our behavior around robots [42], and HRI designers will deliberately implement interaction cues and design elements that help people form an appropriate and effective mental model of the robot to make sense of these interactions. For example, the PARO robot was intended as a therapeutic device for eldercare, that could emulate animal therapy interventions [60]. The designers created physical and verbal interaction mechanisms, including a plush seal-like appearance, soft nurturing sounds, and slow movements, that fostered a mental model of the robot as soft and comforting. Other research has found how relatively simple design aspects influences our mental models, including robot names and pronouns on perceptions of agency [6], and supporting awareness of a robot's knowledge base or perceptual capability on the tasks people ask it to perform [54, 56]. Designing an authoring tool for those who are not experts in HRI design will need to help the content creators apply HRI design insights, such as using speech and movement patterns that align with the intended role of the robot, and planning a role for the robot that meets the end-user expectations for those interactions. However, little work has explored supporting a user's mental model of the affordances of a social robot through an authoring tool, or how a novice programmer might create meaningful social robotics experiences.

2.5 Pilot work informing this study

In two studies prior to this work, we conducted interviews and focus groups with middle school science teachers to explore teacher perspectives on supporting students during homework. In the first study, we interviewed nine teachers about their perspectives on homework, including its utility and their current methods of assigning homework, existing online learning tools, and what additional needs they have for planning and delivering homework [28]. In a follow-up study with twelve teachers, including eight returning teachers from the interview sessions, we conducted co-design focus group sessions with pairs of teachers where teachers used an online collaborative whiteboard to assemble and create elements of a user interface to make their own ideal homework authoring tool (see Figure 2; [27]). Results from this prior work show that science teachers utilized multiple online resources for homework, including short videos, readings, and quizzes. Teachers indicated that becoming more familiar with online tools during the pandemic made them feel more confident and interested in using an authoring tool for creating their own homework guidance. We also found teachers wanted homework to serve as an extension of classroom learning that build on prior classroom activities. In particular, teachers sought to make connections to students' lived experiences and engage students in evidence-based scientific discussions during homework. However, teachers felt many current online learning options do not adequately support socially interactive approaches to learning. When asked how they would train an in-home tutor to help their students, we were often told the teacher would want to "clone themselves" to provide guidance similar to what they provide in the classroom [27]. Teachers felt an authoring tool to create guidance during homework, such as PATHWiSE, would need easy integration with their current planning routine, a low learning curve, and a simple workflow. The focus group sessions revealed how teachers designed a user interface to integrate help and checkpoints directly into the lesson materials, used a drag and drop method of adding guidance to content, and managed the flow of activities using a timeline approach to connect lesson materials together. This study was also informed by other prior work, where we examined and found several facial expressions for the robot that were most easily identified, including attentive, confused, happy, questioning, sad and surprised (See Figure 3 for examples; [42]).

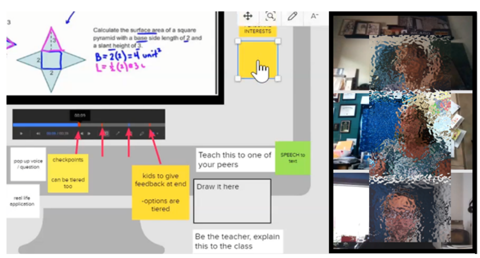

Fig. 2. Online co-design focus group session from prior work with two teachers and a researcher (blurred on right) creating, editing, and discussing the types of features they would want in an ideal homework authoring tool. Yellow squares show actions teachers wanted to trigger at different points in the lesson.

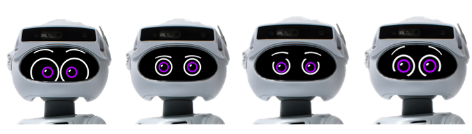

Fig. 3. Robot facial expressions found to be recognizable as emotional expressions that were included in the PATHWiSE prototype design.

2.6 Research Questions

In this study, we build on this prior work to develop a prototype authoring tool to enable teachers to create social learning experiences through student-robot homework interactions. To address our goals of understanding how to design for teachers to create their own robot-assisted lessons and to capture teachers' perceptions of the role of social robots in these lessons, we asked the following research questions:

RQ1: How do teachers use an authoring tool to leverage their pedagogical expertise to create homework experiences with a social robot despite being a novice in robotic programming?

RQ2: What roles and interactions for a social robot do teachers envision while creating robot-assisted homework with the authoring tool?

3 METHOD

To test our research questions, we designed and created a prototype student-robot interaction authoring tool based on previous co-design sessions with middle school science teachers during interview and focus group sessions. In this study, we continue our participatory co-design by examining teacher use of and experiences with the prototype during homework creation sessions. The sessions included teachers creating annotations for a homework assignment and then seeing those annotations acted out by the Misty II robot used in our prior work developing learning companion robots [1]. We analyzed these sessions using a Thematic Analysis [11]. Teachers were compensated $50 USD for participating and the research was approved by the University's IRB.

3.1 Design of PATHWiSE authoring tool prototype

Based on interviews and co-design session in prior studies, we created a PATHWiSE prototype centered around a type of homework assignment where students read short articles that relate to upcoming classwork. We designed the prototype using three design guidelines derived from our participatory work with teachers where the system should provide: (1) teachers with a way to annotate their own digital content rather than grapple with unfamiliar new materials, (2) tools for teachers to incorporate personal guidance similar to their classroom interactions with students, and (3) an intuitive, simple to learn interface. To allow teachers to directly annotate their own digital content, the prototype includes a large central canvas, where a homework reading article, selected by the teacher, is displayed (See Figure 4, left). To provide tools to add guidance, we included a small *annotation* tool next to the article canvas, that allows teachers to add guidance to a specific location in the reading by placing, via drag-and-drop, a speech-bubble directly onto homework materials (See Figure 4, center). This speech bubble represents an *annotation*, that includes text for the robot to 'say'," facial expression for the robot to display, and the location in the article where the robot should take these actions. Teachers add their own text for the annotation, that will be said by the robot, into an entry box to the right of the article (See Figure 4, right of center). Teachers can then select non-verbal emotional expressions to accompany the robot's speech from a drop-down list of seven facial emotional expressions (such as 'happy', 'confused', 'questioning'; See Figure 3) that will display the selected emotion as a facial expression on the image of the robot. A second side panel provides a group selection tool to select and view specific students or groups who should receive each specific annotation (See Figure 4, right) that includes options for all students or pre-selected groups such as students with high interest in science or lower reading ability. In these co-design sessions, we populated the group selection panel with generic student names, such as 'student 1' and 'student 2' and provided samples groups, including 'science interest' and 'reading support.' To increase the simplicity and efficiency of adding annotations we designed the prototype to function within a single HTML-based web page to avoid teachers needing to follow sub-menus or additional windows to create annotated homework. To simplify the learnability of the system we use visual cues, rather than pop-up windows or written directions, to help users understand how to use the prototype, including draggable icons and speech bubbles for text entry to visually cue the teachers that the written text would become the robot's speech. We also added a visual element to the emotion selection tool by updating the robot image to depict the selected emotion.

3.2 Homework Co-Design Sessions

To understand teacher experiences and use of the prototype to create homework we conducted 90-minute collaborative co-design sessions with middle school science teachers ($n = 13$) from different regions of the US, five of whom had previously participated in both prior interview

[1]https://www.mistyrobotics.com/

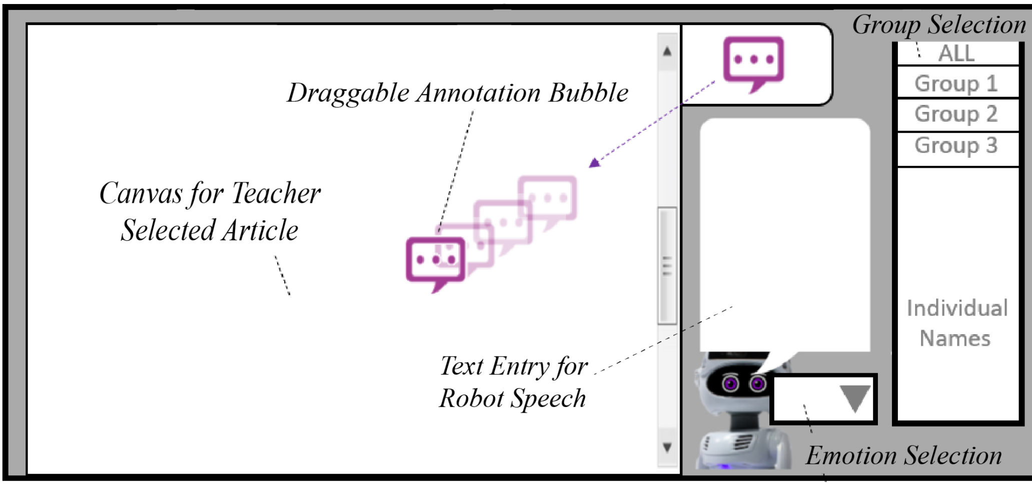

Fig. 4. The PATHWiSE prototype design outline, including large canvas area for teacher selected articles, a draggable annotation bubble to locate guidance in a specific point in the article, a text entry box to write robot speech at that point, and options to select specific groups of students to receive the guidance and different non-verbal emotions to be displayed on the robot.

sessions and focus group design sessions. Teachers had a wide range (3 - 22 years) of teaching experience and one teacher recently took on an administrative role. No demographic information about the teachers was collected. Prior to each session we asked the teachers to send us a PDF of a science reading homework they typically would provide their class. We integrated that reading into the article canvas of the prototype and hosted the authoring tool as a unique HTML page on a university server. Therefore, the prototype was customized for each teacher-participant to display their own reading selection for them to annotate, so that teachers were already familiar with the reading material prior to the study. The sessions were conducted remotely using an online meeting tool for the teacher and researcher to meet. We also included the Misty II robot in this online meeting through a separate computer connecting to the meeting. The robot was operated by a second researcher, but only the robot was visible on screen (See Figure 5, bottom). In this way, we hoped to demonstrate the experience of interacting with the robot, and what the teacher's annotations would sound and look like to a student, even though the robot was not fully capable of autonomous interaction. Each online meeting session was video recorded, with the teacher's consent. The online meeting software automatically generated transcripts that were later edited for accuracy by the research team.

Each session started with an introduction to the learning companion robot, Misty, and a description of the interface and annotation tools. We explained how annotations added to the homework would be voiced by the robot as the student progresses through their homework. Teachers were instructed to place annotations in the location in the reading they would like the robot to begin speaking, but we did not provide specific details of how this would occur in interaction with the student. As the focus of the research was not a test of the usability of the tool per se, we then briefly demonstrated how to use the main functions of the tool and gave time for clarifications and questions.

We then asked the teacher-participant to use the tool to add their own annotations (see Figure 6). Teachers showed their work through a screen-share and were prompted to narrate their thinking,

Fig. 5. During homework co-design sessions the Misty Robot was visible on a separate screen of the online meeting (bottom). The robot was programmed to act out each teacher-created annotation after the teacher completed the annotation. The researcher (blurred upper left) asked the teacher (blurred in upper right) their feedback after the robot acted out each annotation.

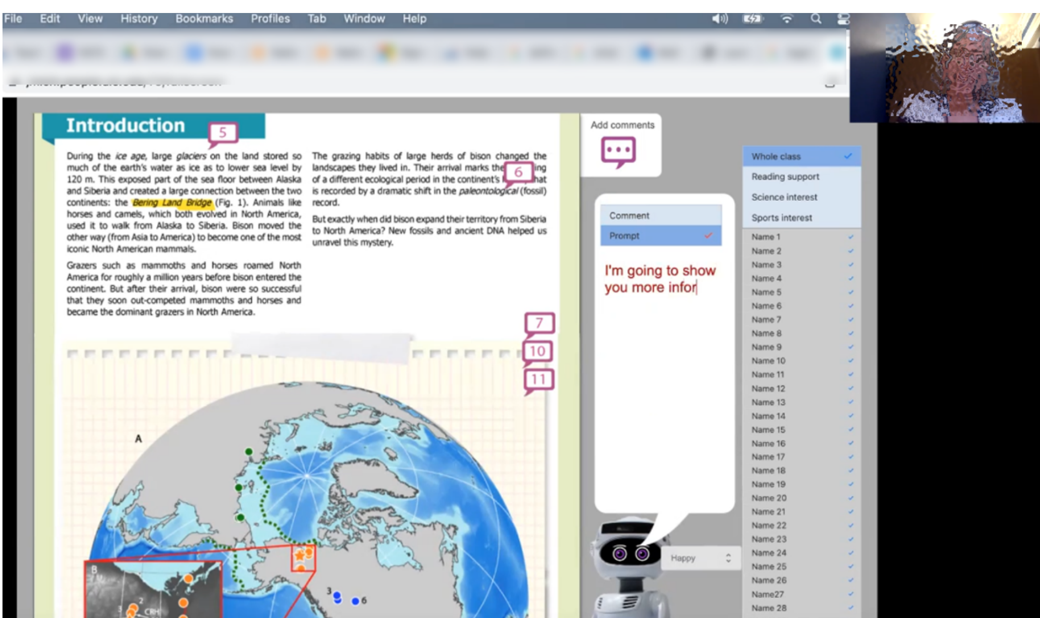

Fig. 6. A homework co-design with a teacher session conducted over Zoom. The teacher (blurred in upper right) is viewing their article and has added several numbered annotations to it (purple text boxes) with text (in red) in the text entry box and selected the 'happy' emotion for the robot's display.

or "think-aloud" as they did so [58]. We encouraged teachers to not only describe how and why they added any annotations, but to also describe how this homework design connected to their teaching practices. For example, when a teacher added an annotation that asked students to define a key term in their own words, the researcher asked the teacher if that was a question they might ask during classwork. After the teacher's first or second annotation, the second researcher prompted the robot to enact those annotations in the online meeting to show teachers what these enactments would look like. Due to the constraints of the prototype's back-end functionality, the robot's speech was live-programmed, including rapid creation of audio files using text-to-speech of the teacher's annotated comments by the second researcher watching the session. We asked the teachers to share their thoughts about their impression of the robot voicing their comments, and then prompted them to create further annotations. During the session they were able to make changes at any time to previous annotations, including comments, emotions, or assigned groupings. At the end of the session the researcher asked open-ended questions, following a semi-structured qualitative interview protocol to investigate their specific viewpoints but also allow for exploration of additional lines of discussion [16]. Teachers were asked about their impression of the system, its usability, affordances, constraints, and what a tool like this may mean to their workflow and classroom or homework practices.

We analyzed the data using a Thematic Analysis approach [11] to qualitatively identify patterns in the data from teachers' perspectives and draw a grounded understanding of their views. To conduct the thematic analysis, five researchers, including the first author and last author, familiarized themselves with the data and created detailed notes from several reviews of the videos. We then generated semantic codes using an inductive approach and organized the data into major categories from these codes, such as 'redirecting student's focus' and 'perceiving robot as extension of classroom.' We then discussed both codes and categories at several stages to find consensus on observations. Some contradictions or disagreements between teacher views, such as whether to promote or limit student choice of tasks, which led us to identify the core reason why each supported such arguments and thereby revealing further insights. From our categories we identified emergent themes through iterative discussion, then co-constructed, and refined finalized themes based on meaningful patterns we observed in the data. As emergent themes were the outcome, rather than systematic formalized coding, we did not conduct inter-rater reliability. This methodological choice is advocated by leading scholars in Thematic Analysis [10], is in line with methodological recommendations for HCI by McDonald et al. [41] and has been described in Klein et al. [36] and Herrenkohl et al. [29].

4 RESULTS

At the conclusion of our Thematic Analysis we found three major themes pertaining to our research questions: (1) teachers' changing perception of the social affordances of the robot changed their approach to annotating homework, (2) teachers used informal roles and classroom-like actions for the robot to support and encourage student learning, and (3) teachers envisioned additional motivational and language supports as well as formative assessment and in-class guidance opportunities. We describe here the three major themes generated from our analysis and support them with direct quotations from the teachers. Each quote is attributed to teachers using their study ID which were randomly generated numbers from 1-30 (e.g., T21). Words appearing in square brackets were added for clarity.

4.1 Theme 1: Teachers' changing perception of the social affordances of the robot changed their approach to annotating homework

Teachers initially created annotations using direct language that typically included a question prompt similar to a homework problem style, but this annotation approach gradually evolved to become more conversational. Teachers explained that their initial strategy was to pose questions at the end of a paragraph or section of the reading to “test what they’ve learned” (T11). Many teachers also added annotations with introductory sentences to prime the students to certain aspects of the reading, such as "Make sure you read these two intro questions before you dive into the reading," which teachers reasoned would “get their [students’] heads into the right space before they start reading” (T5). However, after seeing the robot enact their annotations, all the teachers in the study described changing their phrasing to a more conversational tone to be “like I would use every day in the classroom” and to "meet students on their level" (T48). They also seemed to begin accounting for the student’s perception of the robot, as T11 described they would write some annotations:

> “to make [the robot] more anthropomorphic...like they’re responding to a person, rather than a piece of paper"

This mental re-conception of how to use an informal tone to write an annotation was exemplified by T9 who explained that her original annotations were written “with my teacher hat on” and rewrote them because “I have to think like Misty [the robot]”. Another teacher narrated her thoughts as she made changes to an earlier annotation, explaining “instead of being so formal at this point, Misty [the robot] should be more, more relaxed’” (T5). Many teachers described their later annotations reflected the style and tone of speech they would use in the classroom. For example, T33 said “That’s what I would be saying, I mean, they know that, because I’m like ‘oh my gosh guys tomorrow we’re digging in dirt, we are gonna have so much fun!’". In sum, teachers didn’t seem to initially conceptualize the social affordances of the social robot until hearing and seeing the robot voice their annotations. This change in perception seemed to lead to changes in their annotations to adopt the familiar tone and language they use in a classroom rather than the less personal, formal language of a textbook or worksheet.

In addition to describing changing the tone of the annotations, seeing the robot enact the annotations seemed to lead teachers to want to change their approach from traditional written homework questions to annotations that closer reflect in-class interpersonal connection-making. For example, some teachers took the opportunity to change their initial annotations to refer directly to students’ personal interests and shared experiences. After hearing their first annotation read by the robot, T10 said “I gotta change that ...to ‘Think about your last basketball game or gym class, how is respiration important to you?’" This teacher explained the new type of prompt would get students thinking about respiration, because "they should be able to relate to when they’re playing a game, you know, a sports competition or gym class”. It appeared that this change in types of annotations teachers created was linked to changes in their perceptions of the robot’s social capabilities. One teacher explained her reasoning for this: “So, if I was writing -you know I hate to say this- but historically we would just, like, if this was a homework assignment, they just go home and read it and without stopping to think and that’s it. But if I have the opportunity to add my voice to it or, or Misty’s voice to it, I would take the opportunity to say ‘hey remember yesterday when we got a card-sort?’ So, let’s bring that knowledge in!” (T5). In this way, it seems that teachers’ perceptions of the robot changed to adopt a more socially rich view of the interactions, that in turn changed their approach to annotations. Over time, teachers seemed to see how the PATHWiSE tool and robot interactions could transform homework activities to become interpersonal exchanges that more closely resemble their classroom practices that activate prior knowledge, experiences, and personal interests.

The changes in perspective about the robot’s social affordances also seemed to inspire teachers to add new types of annotations to highlight figures and illustrations in the homework. Teachers appeared to see the social ability of the robot as useful for bringing the students’ attention to figures, that "they would otherwise just fly by" (T33). Teachers also suggested using annotations to connect from the text to the illustrations in ways that may help the student connect with both the content and the robot. For example, one teacher felt they could add an annotation for the robot to guide attention to a picture "by saying 'hey take a look at this. Wait, wait, go back look at that picture again'" (T5). In this way, T5 described a conversational way of using the robot's social interactions to motivate students to look at an important figure. Some teachers described how the robot could do more than verbally direct toward an illustration already in the reading, but that they could also add a new image in the annotation, where "Misty [the robot] could say 'hey look what I found' and then push a picture up" (T32). Again, it appears teachers revised perceptions of the robot interactions allowed them to envision new ways to make annotations to readings that would increase the socially interactive nature of the homework assignment.

Finally, teachers in our study described ways that the robot's social affordances could be used to support students that struggle the most with the material, similar to how teachers use guidance for those students in the classroom. For example, T3 said "You know, it'd be nice to really see something like this help the kids that need it the most, first". Teachers seemed to see how their annotations could guide the robot to attend even more to students "that need the extra help, maybe having, like, more things planted through here for Misty [the robot] to comment about even, just not so much asking more questions, but like, just comments" (T36). Teachers saw the robot vocalizing the comments during homework as a way to reduce the limitations posed by lower reading skills. For example, one teacher said, "I have had students who can't read in middle school. And so, I think having [the robot] read it out loud to them would really work" (T35). Many teachers emphasized the ability to support the student's understanding of science content and terms when, "the kids are still learning the information" (T3), because in science "the words tend to be long and complicated" (T9). Many teachers expressed how well the robot's vocalization would support the needs of students with disabilities or specific learning needs, particularly if the robot were to read some of the homework aloud. As T36 exemplified, "I have one student who's gifted but has dyslexia ... if she's trying to read through this she'd get up after probably a paragraph or so ...but if she *hears* it then she's able to process it very well." Here we see teachers seem to highlight ways that the robot's social interaction might benefit students with specific learning needs the most, and how they might use the PATHWiSE tool to create those interactions.

4.2 Theme 2: Teachers used informal roles and classroom-like actions for the robot to support and encourage student learning.

Robot Roles. Teachers typically described two optional roles for the robot during homework interactions, as an extension or *avatar* of the teacher or as a separate learning *buddy* with its own personality. Some teachers described designing homework interactions with a teacher avatar role in mind that simulate having the teacher at home with the child via the robot, where the robot could "echo what a teacher says, like the nuances of speech" (T11). T33 said it would be:

> "like bringing your own teacher home...she'd [the robot] be the teacher, she'd be me in there, sitting at their house – which I threaten frequently!"

Some teachers who thought of the robot as an avatar desired the robot to emulate their personal style including their use of humor. For example, T36 said, "Misty [the robot] needs some sarcasm" to increase engagement with the material and T35 thought that if you "get the children to giggle they will probably remember it." Other teachers believed the robot should act as if it had its own personality because "Misty is in fact her own being...I think she needs to be a separate thing. It's not a teacher avatar" (T9). Having the robot embody an independent personality was often described as easier to achieve, as the robot would not need the content knowledge of a teacher "and it could be that Misty just says something like 'um that's a good question, that's one you're gonna need to ask your teacher tomorrow'" (T9). As an independent personality, "Misty doesn't need my content knowledge, Misty just needs to question, and come up with good questioning. That way, kids think and question about what they just said" (T5). Teachers further described how this independent personality could represent a study friend or buddy for the student that would "just be basically mimicking, you know, an elbow partner, like when you're sharing something out with your partner" (T3). They also saw the value in this social role to be "a powerful thing because some of my – particularly the lower learners – struggle with writing...but they seem to have no trouble articulating, so if Misty is there to ask those questions -boom! that's a great thing" (T32). Many also described the robot's role simply to be a friend providing companionship. One teacher explained how a student might think "'I'm not alone on this study island!', you know, 'I got a study buddy, yeah!'" (T32).

Robot Actions. Teachers suggested many robot actions and interactions during use of the PATHWiSE prototype they felt would improve the learning experience, including responding to student answers, intervening when students appeared stuck, or providing correct answers. Although neither the PATHWiSE interface nor the researcher indicated that the robot would be able to respond to the student, teachers commonly described a response action feature that they considered highly advantageous over existing homework activities. In particular, most teachers considered the students' thinking and motivation would be supported by robot response actions that include "some type of an affirmation" (T10), or the robot saying "oh, my goodness you're right, you remembered so many things" or "wow that was great" (T3). Teachers believed these affirmational responses would help students, "to move on and keep working so they don't just get hung up on whether it's the right answer" (T10). Teachers also saw how the robot's social skills could help students when stuck. For example, T39 suggested "it would even be interesting to put in a comment that's like 'Oh, are you stuck, like here's a little bit more' to kind of explain it, right, to give almost more of that social interaction that would, like happen in the classroom". Some teachers also wanted the robot to provide the correct answers but acknowledged there may be technical limitations to the robot's understanding of the child and suggested that 'generic' answers would suffice to continue the dialogue. For example, T48 would want the robot to respond "'you're wrong because x,y,z, that is why you are wrong'" but acknowledged that "it's not like [the robots] have to say the right answer or like 'hey you got it right', if they said like, 'ah that's good, here's what I'm thinking'". In this way, the teacher seems to suggest that the robot action should acknowledge the students answer and then pose the correct answer as the robot's own thinking. Teachers also recognized the robot would not have the domain content knowledge of the teacher but could simply repeat the student's answer back to them, "then [the student is] more likely to hear what they're saying and then that might engage them to edit their thoughts in a way. You know, so it requires more thinking"(T11). Here, the teacher seems to feel that if the robot were to repeat the students answer, it might help foster further revisions in thought about those concepts. Similarly, teachers suggested the robot could prompt the student for more depth of thought by asking, "'why did you think...' you know, questioning 'hmm, why did you say this answer?'...Productive struggle for students is a wonderful thing, so we wouldn't want to just say 'nope you're wrong here's the right answer'"(T32).

In general, we found that teachers seemed to see the robot in the role of a social agent that could either emulate the teacher or have its own personality, to support students at home in similar ways to informal classroom interactions. After envisioning the robot's role and relationship to students, it appears teachers then expanded the potential for robot actions during homework to match methods from their classroom teaching. Both the presence of the robot as a social agent and the classroom-like interactions opened up new homework interaction paradigms that the teacher could employ using PATHWiSE.

4.3 Theme 3: Teachers envisioned additional motivational and language supports as well as formative assessment and in-class guidance opportunities

Supporting motivation and linguistic needs. As one teacher told us, "For students that, you know, don't have an adult home with them all the time ... they'd have this extra resource" (T36). Beyond just being an animated presence, they considered the social affordances of the robot to represent "a companion there that's helping them through this...there to listen and to guide...and so they can talk it out to somebody, even though they might be by themselves"(T3). Importantly, teachers considered the robot's presence to "not be judgmental" and would "just be there to help and to encourage" (T3) student's at-home learning. Teachers also thought the motivational support "will improve the overall social emotional learning that students are doing" and would "help their long-term understanding of concepts" (T42). T35 summarized,

> "I think the concept of having a robot assistant who could help keep the students engaged and provide them like almost instantaneous personalized feedback on how well they're doing, in a non-judgmental manner, is brilliant. It like, it could possibly revolutionize the way children learn and engage with content and material."

Many teachers saw additional support for students facing difficulties with writing, as in the case with T33 who explained her class has "a lot of kids who are on [Individualized Educational Plans] and they don't do the lab reports the way the other kids do it, they just come and talk, they talk about it to me, and so, this to me would be a phenomenal way of differentiating" (T33). In this way, the teacher seems to describe how the physical presence of the robot might help students provide verbal responses, when their written language skills are still developing. Teachers also expressed that authoring student-robot interactions for English Language Learners (ELLs) could reduce barriers faced by students engaging with technical science articles alone at home. T5 told us, "Science is probably the most difficult for ELL kids. This article has words that even English [as their first language] children struggle with, and then you throw in a language barrier on top of it." This teacher described some of the nuanced needs for ELL students, who may be verbally fluent but not fluent in the written language. This idea led to a possible scenario where the robot could translate and read out the article in the student's own language because for example some Spanish speaking "kids don't want the Spanish document, some of them actually cannot read the Spanish document. They're at home, they're hearing Spanish, but they're not reading it" (T5). In these ways, teachers envisioned applications and benefits for robot-assisted learning that went beyond the scope of direct homework support and focused on motivational features of having an encouraging companion and the linguistic supports of affording verbal communication on written texts.

Formative Assessment and In-Class Guidance. An additional way teachers saw to create student-robot interactions was to solicit valuable insights into their students' learning that would come from verbal responses to the robot. Many teachers considered capturing student's verbal answers during homework to be "a quick way to show me what I need to start the day with" (T9). Teachers saw these verbal responses as a possible source of formative assessment where teachers would want a transcribed spreadsheet of student responses "to quickly scan through and find misconceptions" (T10). These collections of student responses could help determine subsequent classroom instructional directions or topics. For example, T10 told us that "if I'm scanning kind of through [student responses] quickly before class or whatever, and every kid is wondering about poop, because they will, because I teach middle school boys...I'm going to be like okay I gotta hit that right away" (T33).

Teachers also suggested extending the robot's role into the classroom, where "she's like part of the class...and if she could work with kids in class, I mean like she'd be your little assistant" (T33).

Teachers considered many of the social affordances of the robot would also solve challenges in the classroom. For example, T35 explained that:

> "one of the biggest problems, especially with middle school, is when you're providing small group instruction you need to ensure that everybody else is on task. So, it'd be really cool to be able to utilize this in the classroom where we can switch to small group settings and I can make my way around, but the kids are also interacting with Misty and she's helping make sure they stay on task."

These ideas demonstrate additional ways teachers started to expand the unique interactions the system could facilitate based upon emulating aspects of the teacher's own expertise and interpersonal skills, including supporting their motivational and language needs, gaining insights into their thinking, and helping facilitate classroom instruction.

5 DISCUSSION

In this study, we found that despite lacking technical expertise in programming a robot, teachers were able to use the PATHWiSE prototype to apply their teaching expertise to design homework that transforms the activity from isolated formal practice to a social informal experience. It appears that seeing the robot enact initial annotations was crucial in honing their approach to creating annotations in a conversational style akin to teacher-student classroom interactions rather than traditional homework. **We believe that these changes in perspective on writing annotations were related to an emerging view, or mental model, of the social affordances of the robot.** In short, it appeared the teachers had little difficulty utilizing their teaching expertise for adding social and interpersonal supports for students once their perspective of the robot's capacity for social interactions took shape. These findings also illustrate the unique needs for teachers and other designers of computer-supported collaborative activities, who are experts in designing these activities in one context (*e.g.,* the classroom), but are novices in designing in a new technological context (*e.g.,* social robotic interactions). In our specific case, teachers are both experts in curriculum and instruction and novices in robot programming. Thus, an authoring tool for teachers to create robot-assisted homework activities must account for both levels of expertise. We believe this insight has general design implications in the HRI, and CSCW communities. Based on these findings we discuss theoretical and practical implications, including theoretical contributions on how mental models are shaped while designing computer-supported social or collaborative activities and practical considerations for designing authoring tools to best facilitate effective social interactions.

5.1 Shaping Mental Models to Create Social and Collaborative Experiences with Technologies

In our study, we found that homework activity design was determined by three key factors: (1) the teachers' emerging mental model of the technology, (2) teachers accounting for students' or end-users' perceptions of the interactions, and (3) a mapping of teacher-student or human-human interaction paradigms that act as a template for the technology interactions. We believe that recognizing the role of each of these factors in shaping the mental models of interactions with technology is crucial to designing an authoring tool for non-experts in the technology, such as teachers, to deftly apply their teaching expertise.

Emerging Mental Models. The teachers in our study did not immediately seem to utilize the socially interactive capabilities of the robot. We intentionally structured our design sessions to try and demonstrate the robot's social capabilities by introducing the authoring tool as a means to create *social* homework experiences and a demonstration of the robot's social behavior. Yet, each teacher in the study started with what they eventually described as "being so formal" (T5) in creating annotations that resembled traditional homework questions. When those initial annotations were read out loud by the robot, the mismatch between what the teacher wrote (in a formal tone) and how the robot said it (in an informal friendly tone) was readily apparent. We believe that observation may have helped reshape the teacher's mental model of the robot to go from what Dautenhahn describes as a formal "assistant" role to more of an informal "companion" role [22].

To explain why teacher mental models did not initially fully account for the social capacity of the robot, we believe the context of authoring homework activities may have influenced their perception of the robot. It may be that teachers' mental model of the robot in relation to homework activity was initially framed by their experiences in creating homework as a formal assessment mechanism using other educational technologies (*e.g.,* Engrade from McGraw Hill [27, 30]). In this way, teachers may have initially shaped their mental model of robot activity to conform to formal homework, such as quizzing students. This finding is similar to how older adults formed an initial mental model of a social robot based on prior experiences with other advanced communications systems that changed after interacting with a robot [61] and informs our understanding of mental model formation to include contextual factors such as activity paradigms. That is, mental models of robots are known to be based on the shape and function of the robot [38] as well as people's prior experiences [57], but **in this study we demonstrate how mental models are also shaped by the *context*, in this case online homework, in which the robot interactions take place.**

Emerging End-user Interaction Perspective. Seeing and hearing the robot enact annotations within the homework seemed to be the needed catalyst for reshaping teachers' mental model of the robot as a social companion-like agent. This shift to social companion roles for the robot seemed to trigger two new mental model recalibrations; their model of student perspectives during interactions and the paradigm for the structure of the homework activity. First, as teachers saw the potential for social, companion-like interaction, they seemed to newly consider how students would perceive the robot and revise their concept of the student-robot interactions to think about how the student would be "responding to a person, rather than a piece of paper" (T11). For example, since the interactions would be more informal and personal, teachers thought the robot might help kids move away from getting "hung up on whether it's the right answer" (T10) and focus more on the intellectual process of engaging with the robot about the ideas themselves. In this way we believe the teachers' experience of seeing the robot enact the specific interactions they designed was necessary for them to reconsider how students would perceive and interact with the robot. This insight may be similar across other applications and technologies. Authoring tools can allow novices to technologies or computer programming to create interactions within their applied areas, such as retail sales, manufacturing, or care for older adults. **importantly, such technological novices may need firsthand experience of social interactions with the technology in context to better account for the end-user experiences they are designing for.**

Emerging Interaction Paradigms. The change in perspective of how students perceive the activity, based on the robot's social companion role, seemed to then adjust what learning or interaction paradigm teachers evoked in considering how to structure a homework activity. The shift in perspective moved to align homework activities with student-teacher and student-student classroom interactions, rather than the student-paper interaction paradigm teachers seemed to initially envision. In this shift, teachers began to infuse their use of humor and guidance and think of the use of verbal exchanges for interactions they designed. For example, teachers often came to think of ways to use the social interactions with the robot to slow students down to consider text and figures that at home "they would otherwise just fly by" (T33). This finding is consistent with student perceptions that reading with a robot slows them down to think more about what they read [45]. In this way, teachers modeled homework after classroom interactions, where the teacher could guide student attention to key figures, stop their progress to think, or have them re-read a section. Teachers also seemed to demonstrate this new interaction paradigm by expanding their vision for the functionality of the system to include other areas of support such as motivational and linguistic needs, and even suggesting the robot accompany the students in class. While experts in human-robot and human-computer interaction may readily see how adding new socially rich interactions to an activity can and should change interaction paradigms, it may not be apparent to novices with those technologies. We believe that **effective calibration of a mental model of the robot's or technology's social capabilities and a perspective of the end-user's experience with the robot or technology are needed to help expand the possibilities for effective interaction paradigms.**

In sum, we believe this study demonstrates the intricate balance involved in shaping mental models of social robot capabilities, perspectives of human-robot interactions, and the interaction paradigms applied to these computer-supported social activities. In this study, teachers' emerging mental models of the robot shaped and was shaped by their perception of *how* students would interact with the robot as well as *what* learning activities were afforded by those types of interactions. This finding extends outside of HRI and educational technologies as it demonstrates how professional expertise and experience shapes the use of an authoring tool to create social and collaborative experiences with technologies. This relationship may provide insights into persistent issues in other CSCW areas, such as industrial robots, where engineers with expertise in automation design seem to try and fit collaborative robots into a traditional automation paradigm, rather than change the paradigm to better suit the affordances the new collaborative robots [46]. Within this example, human-computer interaction researchers as well as CSCW and HRI researchers might rethink the theory and design of authoring tools for collaborative robots to better shape an engineer's mental model of the collaborative robot. We explore these practical implications further in the next section.

5.2 Designing Authoring Tools for Social or Collaborative Activities with Technologies

Based on our findings, we believe there are several key design implications for creating authoring tools that allow technological novices, such as teachers, to create their own computer-supported social or collaborative interactions, such as robot-assisted homework. These design implications include: (1) embedding the authoring environment directly into a representation of the applied interaction space, (2) simulating the authored interactions within the authoring environment, and (3) defining effective interaction roles that exemplify the social dynamics of the technology and conform to end-user expectations by providing examples and templates.

Embedding the authoring environment directly into the applied interaction space. In our design of the authoring tool, we placed the annotation tools directly next to canvas containing the readings teachers selected for homework assignments. Teachers in our study seemed to like being able to quickly drop an annotation to add a comment or prompt directly into the homework activity, as it simplified viewing the overall trajectory of the interaction. This approach simplified authoring the interaction by allowing teachers to sync actions they wanted the robot to perform with the time or place within the interaction that they wanted the action to be triggered. In a way, the homework scenario of reading an article helped provide a representation or map of the activity space because teachers could anticipate a relatively linear flow of activity as students read each line. Within educational contexts, this activity mapping could also be done using lesson plans or worksheets to represent the interaction space. In other contexts, such as retail sales, the authoring tool might start with a diagram of the retail store to map the activity or interaction space so that interaction authors could directly annotate the diagram with different interaction scenes or dialogue options as explored by Cao et al. [14].

This method of creating a map of the interaction space and annotating that space with robot actions may be well supported using a trigger-action programming approach [39]. Teachers, or other interaction authors, can place annotations on the map that would indicate a trigger point. The contents of the annotation, including comments, non-verbal behaviors, or movement cues, would be stored as the associated action output. A trigger-action approach would also facilitate integration into a robot's software architecture, as trigger-action pairs created in an authoring tool can be stored in database systems such as SQL and can be incorporated on-demand into a hybrid state-machine/decision-making robot interaction design and deployed through REST APIs [24, 35].

Simulating the authored interactions within the authoring environment. In our authoring tool design, teachers added text into a word bubble image connected to an image of the robot. The goal was to support teachers forming an effective mental model of the social capabilities of the robot through visual cues. In particular, we hoped they would consider how text they entered would be spoken by the robot and how the non-verbal/emotional cues they could select would change the social appearance of the robot. However, we found this approach to be ineffective, as teachers' initial annotations did not fully utilize a social or informal approach. What did seem to positively influence the teachers' mental models was seeing and hearing the robot enact those comments. We believe this richer multi-modal demonstration of the robot's social abilities was much more effective than the static representation of the robot in helping calibrate an appropriate mental model of the robot. That in turn subsequently had an influence on considering the student/end-user's perspective and on expanding the possibilities for more social interaction paradigms. It may not be feasible for teachers or other interaction authors to have the physical robot enact annotated activities, so **we recommend that authoring tools incorporate a simulated robot or digital agent to demonstrate or enact each interaction that the author creates**, using automated text-to-speech and 3-Dimensional robot movements. In line with a richer multi-modal display, it may also be beneficial to demonstrate these simulations within the context that the interaction will take place. For example, in an elder care scenario, it might help to place the simulated robot in a small room with an older adult, as well as other key artifacts (*e.g.,* medications) for that interaction.

By incorporating robust simulations into the authoring tool, we can help close the loop between generating inputs in an authoring tool (*e.g.,* annotations in PATHWiSE) and visualizing outputs (*e.g.,* social robot discourse) that are not directly linked to the input device. Some authoring tools, such as the NAO Choreographe, include a simulated robot to demonstrate movements, but does not include the verbal outputs that strongly influenced our teachers. Designing for visualizing outputs may be part of the unique set of design needs for non-experts to learn *how* to design robot interactions, but these visualizations may only be necessary in early learning of the authoring tool and can be removed or faded over time.

Defining effective interaction roles for social robots by providing examples and templates for dialogue and behaviors that exemplify the social dynamics of the interactions. Our findings suggest that teachers had different perceptions of the robot's role, either as an ambassador of the teacher or a learning buddy, which helped them build an emerging mental model of the robot's capabilities. Importantly, the teachers desired the robot to build a relationship with the student by embodying a personality through the use of emotional expressions and everyday language. While the teachers were able to voice such interactions, they appeared to struggle to capture the nuances of spoken language when actually writing their annotations. Therefore, we suggest the **authoring tool should help teachers, or other non-expert programmers, to write interactions that conform to effective social roles for the robot that conform to end-user expectations**. For example, current evidence suggests that most children perceive learning companion robots as a friend or buddy [13, 44], and aiding teachers in authoring interactions with that role in mind could be beneficial. For example, sample annotations could be incorporated into the authoring tool with robot comments written to exemplify the appropriate interaction style, or interaction templates could be provided to show effective interaction patterns for an activity. In a classroom or homework scenario, these samples could explicitly exemplify an informal, friendly, and conversational personality of the robot through editable patterns of activities. In other contexts, such as in healthcare, a more direct conversational role may be more appropriate and sample annotations and templates could reflect that interaction style. In this way, authoring tools can guide authors to creating more effective and socially appropriate interactions. Work in developing authoring tools for robots in other applications could also benefit from empirical work that identifies end-user perceptions of the robot (*i.e.,* what role older adults see the robot in during eldercare interactions) and authoring tools to facilitate designing interactions to adhere to that role.

6 LIMITATIONS AND FUTURE WORK

We recognize a few limitations of this study and describe here future work that could address these limitations. First, we have highlighted connections between changes in teachers' annotation approaches and their mental models of the robot, but our study design limits our ability to make causal claims about this connection. Future work that includes comparative conditions would strengthen our theoretical understanding of this relationship. Next, this study was conducted with teachers using one real assignment they have used in their classroom, but it was not done in the context of their actual classes or curriculum. In our testing scenario teachers may have used the authoring tool differently or have a different vision for student-robot interactions than they would in their real classrooms. We also are limited by having conducted this work via online meetings with teachers. This allowed us to reach a broad range of teachers, but again may have influenced the way they used the authoring tool and their responses during design sessions. Finally, this study only looked at the teacher's use and perceptions about the authoring tool and the robot but did not consider the student perspectives and experience. Future work on developing these types of authoring tools would benefit from testing within the actual context of their use, in-person testing sessions, and inclusion of the end-users of the robot interactions. We plan future work with this in mind that will include more formal usability testing, research on student perspectives, and tests of robot-assisted lessons within the context of real classrooms.

7 CONCLUSION

In this study, we demonstrate how the design of an authoring tool can aid programming novices (teachers) in the creation of computer- or robot-supported social activities (homework). We have shown how, with an emerging mental model of the social robot, teachers can apply their pedagogical expertise and classroom experience to create these interactions despite being a novice in the technology. The future of human-robot interactions and designing for computer supported social activities would benefit from helping non-expert programmers to create their own custom interactions in applied fields such as education, collaborative work, and eldercare. Authoring tools will be needed to allow people with expertise in those areas to integrate robot interactions in those fields. Access and support for programming these interactions, informed by HRI and CSCW research and design, will allow teachers and others to apply their expertise to robot interactions using these new authoring tools. Advances in this area will be a key part of taking advantage of the increasing power and possibilities of robotics and other social computing technologies in many areas of modern life. We believe this work makes important contributions towards these advances and will help guide future work on authoring tools for human-robot interaction and computer-supported social activities.

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