Identifying Student Communication Strategies Involving Spatial Information

Luciana Debs
School of Construction Management Technology
Purdue University
West Lafayette, USA

Sean Brophy
School of Engineering Education
Purdue University
West Lafayette, USA

Cecilia Espinoza
Dept. of Youth Development and Agricultural Education
Purdue University
West Lafayette, USA

***Abstract*— Spatial ability and effective communication are considered important skills in the engineering and technology fields. However, little research has been done to assess how engineering or technology students communicate spatial information. Effective spatial information can help engineers and technologists describe their design, as well as how parts of a design are assembled into a final shape. In this study, researchers aimed at identifying strategies used between two peers, referred to as a dyad, as they communicate information to transform a 3D virtual model into a physical scale model. The focus of analysis is on the metacognitive strategies dyads used to identify difficulties in communication. A quasi-experimental design was used to observe the processes used by 6 dyads of graduate students from engineering technology and technology fields. Quantitative and qualitative analyses were used to identify common communication patterns and determine when participants decided on a change of communication strategy. Results show that only two out of six dyads reproduced the model correctly. Successful teams developed an assembly strategy prior to building and used task monitoring to check for misplaced pieces. Less successful teams relied more on repeated instructions to manage miscommunication.**

Keywords— communication skills; problem-solving; team skills; metacognition; visualization

I. Introduction

Previous research has established the link between spatial ability and students' performance in the Science, Technology, Engineering and Mathematics (STEM) fields [1]. Moreover, the rising importance of team-based work and effective communication within companies has been reflected in the Accreditation Board for Engineering and Technology (ABET) student outcomes 'd,' "an ability to function on multidisciplinary teams," and 'g,' "an ability to communicate effectively" [2].

The importance of effective spatial communication can be seen in the construction industry. During the construction of a building, much of the assembly takes place at a jobsite which is usually in a separate location from designers. When design problems emerge during construction, project engineers must effectively communicate the issues and their locations to designers in order to define the best possible solutions. In fact, effective communication is seen as an essential element of construction project success [3].

Effective communication is important not only in the construction industry, but communication skills are considered essential for all professions in the 21st century [4]. Effective communication of spatial ideas is essential for developing complex ideas around ill-defined design problems. However, little research has been done to assess STEM students' abilities in verbally communicating spatial information. Previous research indicates several situations during which verbal communication would either supplement or complement the use of visual artifacts such as drawings and 3D models during the design process [5]. Therefore, being able to accurately discuss design information, which may or may not include spatial information, is essential for project development.

Also, as a team engages in a task involving communication of information, they must use metacognitive skills to plan and critically evaluate their progress [6, 7]. This task in communication require students to monitor what and how they convey information correctly and validate that the information was received and implemented as intended. Much research has been done to understand individual metacognition and its relation to learning; still, much needs to be researched to better understand shared cognition, which takes place in collaborative environments [8].

This paper explores how students regulate communication during an assembly task and especially when they face difficulties in communication of spatial information. The paper uses the following guiding question: What strategies do two peers use to communicate spatial information to one another while troubleshooting the construction of a physical model from a 3D virtual model? This assembly task was chosen because it presents a clear goal to achieve. The task requires one person to translate a visual model into words and assemble steps that another person must then use to construct the object. This makes the process observable to the researchers.

Previous research indicates that teaching metacognitive strategies may improve students' metacognitive abilities [7, 9]. And, by identifying which strategies successful and unsuccessful student dyads use, the researchers intend to better understand metacognitive action processes that could influence students' ability to effectively communicate spatial information. The ultimate goal is to develop future training that could improve students' communication of spatial information.

II. Background Literature

A. Metacognition and Metacognitive Strategies

Metacognition is essential during any problem-solving activity. Metacognition is what good problem solvers use to critically plan and implement a task. These skills help them clearly understand their goals and identify when they have correctly met these goals. Some important metacognitive strategies include predicting, checking, monitoring of tasks, and asking questions [6, 7, 10].

Researchers suggest that training to enhance metacognitive skills in learners is possible and desirable [6, 7, 10]. In addition, even though expertise is usually correlated with better problem solving skills in the experts' domain of expertise, research indicates that this may not always be true. Reference [11] argues that experts also experience difficulties in problem solving that can be attributed to a deficiency in flexibility or in the ability to change procedures during a task. Experts' highly structured knowledge systems, which are necessary for retrieving that knowledge, may prevent them from adopting new strategies and approaches [11, 12]. The inability to be flexible may increase problem solving times decrease the creation of new knowledge. However, research also indicates that novices who are faced with difficult information-seeking tasks tend to rely more on trial-and-error strategies, while experts establish criteria and goals for their problem-solving actions and monitor their progress for each step [12].

Changes in strategies are necessary to deal with unforeseen situations. While analyzing how students solve mathematical problems, researchers have found that the higher achieving students could apply different strategies successfully, as well as take the time to verify their answers against the problem statement. Mistake recognition, adaptability, and expression of thinking were important metacognitive skills those students used in the problem-solving task [13].

In summary, metacognitive skills are critical to a learner's ability to identify when a problem exists and to generate potential steps to solve the problem. Without these skills, a learner can go blindly down a non-viable solution path. If the path is followed too far, it can be difficult to repair. For example, if a miscommunication occurs and is not detected early, the miscommunication issue could propagate. Therefore, early detection can be critical to finding a viable path in a timely manner [14].

B. Mental Models and Shared Mental Models

Mental models are defined as organized knowledge structures that allow people to predict, explain, and describe events in their surroundings [15]. They are simplified versions of the real world that people use for reasoning and making sense of the world [16, 17]. Mental models are also used to integrate knowledge needed to perform a specific task at hand [18]. Through reasoning, mental models help people deal with existing variables by organizing information into meaningful patterns they can later recall [19]. For example, expert chess players can recall familiar positions on a chess board because of their considerable exposure to common layouts; this helps them plan their next move. In general, experts are normally able to recall large chunks of information in their domain of expertise [20].

Even though mental models are an individual representation of reality, few people use their own mental models for reasoning without the contribution of peers, and even fewer people work outside group environments. In order to understand how teams function when solving a task, researchers developed the shared mental model theory [19]. A shared mental model results when the mental models of dyads in a task overlap [21]. This overlap accounts not only for team members' anticipation of the other members' needs but also indicates a better capacity to adapt due to changing demands and improved task coordination [15, 17].

In order to develop a shared model, teams exchange information through communication and interaction [22, 23]. Researchers studying the feedback process in command and control situations found that information transfer and monitoring of situations are crucial for success [23]. Likewise, information quality and feedback from others are essential for the transfer of the characteristics of a model [24]. Through communication, team participants are able to develop an iterative process of refining their mental models, adjusting them constantly in order to achieve common ground [15, 22]. Therefore, shared mental models influence teammates' strategies, which allow the team to successfully coordinate their actions and quickly complete their task [15].

C. Analogies

Analogies are another kind of mental model used to organize and process information. Both organizing and processing information involve the recall of previously stored information within a familiar base domain that can be used to process, or infer, new information in a target domain. The use of analogies can help build and structure mental models to formulate new knowledge. Researchers have found that, although metaphors are not as useful for understanding the concept itself, they are helpful for understanding how different concepts relate to each other [25]. Analogies are most often used by novices because they help make sense of information in familiar terms. However, when novices wrongfully perceive something as an analogy, without considering procedural implications, the outcome may result in failure [26]. If the analogy works on only one superficial dimension of the target and base domain, then the analogy will be unproductive and potentially confusing [27]. Therefore, poor analogies may lead to ambiguity, which can be problematic unless the speaker and listener understand the limits of the analogy.

D. Verbal Communication of Spatial Information

Transforming spatial information into verbal information is also a challenge. Reference [28] studied how communication patterns affect performance of a spatial-related task. In the task, pairs of participants worked together to communicate spatial information in order to locate a target in an electronic display. The respondent had to communicate to the instructor where the target was placed in relation to other images in the display. The respondent's display was rotated in relation to what was presented to the instructor, and all the images were two-dimensional. They found that individuals' spatial abilities were not as effective as their communication patterns in predicting error. Therefore, in reference [28], effective communication was indicated as a better predictor of success than spatial abilities. These researchers also found that in audio-only situations, the communicator was more attentive to the needs of the information receiver as compared to the video setting, when non-verbal cues could also be used. During video communication, much of the transformation of spatial information that should have been performed carefully was overestimated by participants, leading to errors [28]. Therefore, in the present study, visual cues (e.g. gestures, facial expressions, body language) were controlled by using audio-only communication.

III. Methodology

This study was developed as an exploratory study to improve understanding of the factors and strategies influencing verbal communication of spatial information within science, engineering, mathematics, and technology disciplines. The descriptive goals of the research question require a qualitative research methodology. In this study, a reflective communication task, similar to what reference [28] proposed, was used as a stimulus for dyads to engage in communicating and processing spatial information.

A. Sample Description

This task was completed by six dyads (comprising a total of twelve students) of technology graduate students. The range of technology graduate programs at the authors' university is wide. Participating students were from the departments/disciplines of construction management technology, industrial technology, technology leadership and innovation, computer graphics technology, and computer network and information technology. Participants in each dyad were always from the same department. This pairing of participants was to control for variability in participants' vocabularies and references. An invitation to participate was extended through an e-mail sent by each college department office to their current graduate students. Participants were not financially compensated for their time. Researchers did not control for the level of familiarity within dyads.

B. Task Description

The task involved one dyad member (the communicator or 'C') communicating the spatial information about a virtual model to the other dyad member (the receiver or 'R') who assembled that model using wood blocks. Peers could not see each other's work and, therefore, had to rely on verbal information transfer and peer feedback to perform the task.

A virtual model of a 17-piece block "house" structure was used (Fig. 1) as stimulus for the experiment. The design of the house contained the basic features of four walls and a peaked roof that most likely relate to participants' ideal models of a house. The "house" model had a few unique features to facilitate the need to deal with novel, or ill-defined, aspects of the prototypical "house". The model was generated with 3D modeling software and uploaded into an augmented reality software. The model was displayed on a 10" tablet given to the communicator. The communicator had a printed marker that the augmented reality software used to index the desired model. The communicator could manipulate the marker to see various viewing angles of the virtual model presented on the tablet screen.

During the meeting time, each participant was asked to first complete a spatial ability test and then to complete a pre-task questionnaire. Then, each dyad was given three minutes to discuss any naming conventions or strategies for the task performance. After the three-minute dyad discussion, students performed the dyad task for 12.5 minutes and then answered a post-test questionnaire. The 12.5-minute duration was determined through pilot tests based on the average time of when students became either bored or frustrated with the task.

Dyad participants sat back to back at separate tables. The receiver was provided with a set of 100 wooden blocks on their table (in four different colors and nine different shapes). They used the blocks to assemble the model described by the communicator. Students were video and audio-taped for content analysis. Video focused on their hands and models to better identify the moves they used to support their part of the task.

C. Data Analysis

The research question for this study targets the key actions and strategies participants used to achieve their part of the assembly task. Researchers focused on identifying and coding specific events related to this question. The data was analyzed by two independent researchers using NVivo software. Researchers used structural coding [29] to organize data into three main nodes: communication breakdowns, assembling strategies, and problem-solving strategies. Communication breakdowns were defined as an event in the communication process when one student could not understand the information conveyed by the other party or when they identified issues with their physical model construction. Communication breakdowns usually led dyads to switch from an assembly to a problem-solving mode.

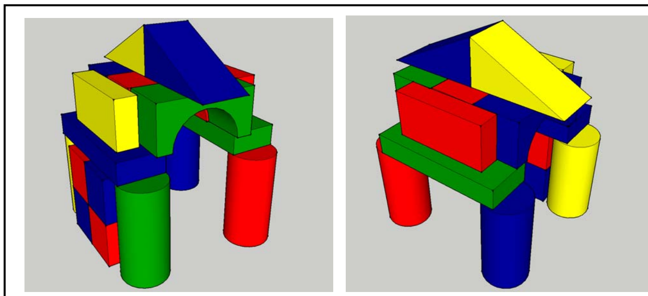

Fig. 1. Model used in the test

Coding for communication breakdowns, assembly strategies, and problem solving strategies allowed researchers to define which strategies were overlapping and which were specific to the problem-solving phase. The nodes were further divided into subcategories and are presented in the results section. Inconsistencies were discussed between the two coders until a final decision was reached. The resulting post-negotiation was an inter-rater weighted average Cohen's Kappa of 0.84 with an agreement of 98% for the data from all six groups. A short description of each group's results and strategies is provided in the results section.

IV. RESULTS

A. Summary of Results

Dyads demonstrated various levels of success and various kinds of problem solving strategies associated with the assembly task. The dyads displayed similar strategies and difficulties while managing the task; yet, each demonstrated different problem solving and metacognitive behaviors that could relate to their success.

The six dyads can be organized into three distinct categories of success, including complete and correct, complete but incorrect, and incomplete. Only two dyads (D1 and D2) successfully completed the task in the allotted time. D1 completed the task in six minutes and eleven seconds. D2 completed the task using all twelve minutes and 30 seconds of task duration. D3 and D4 believed they had completed the task correctly in less than the task duration; however, some pieces were misplaced or were not placed in the model. Finally, two dyads, D5 and D6, were not able to finish the task in the designated time.

All dyads experienced some sort of breakdown of communication that resulted from miscommunication of spatial information. Also, these miscommunications involved at least one of the two errors (a, b) associated with pieces shown in Fig. 2. Problem 'a' refers to the placement of the three middle 'bridge' pieces and problem 'b' refers to the placement and rotation of the smaller rectangular pieces on the sides of the bridge pieces.

In order to best describe the processes used by students, a summary of each dyad's approach to the problem is presented. Table 1 summarizes the findings for the number of pieces placed in the model at the time of completion, number of wrong pieces placed in the model at the time of completion, time, and number of iterations for each dyad. An iteration is defined as a verbal instruction by the communicator and a remark by the receiver.

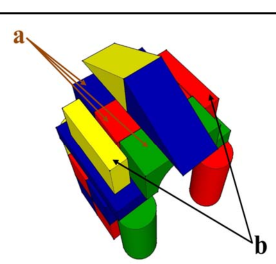

Fig. 2. Most frequently misplaced pieces (a, b)

TABLE I. DESCRIPTIVE STATISTICS

	Dyads					
	D1	***D2***	***D3***	***D4***	***D5***	***D6***
Total pieces in model	17	17	17	15	11	8
Wrong pieces in model	0	0	3	3	5	2
Total time spent (seconds)	371	750	683	640	750	750
Iterations	138	241	182	152	278	181
Iterations / second	0.37	0.32	0.27	0.24	0.37	0.24
Duration of Problem Solving (seconds)	42	230	226	206	373	358
Duration of Problem Solving (% of total time)	11%	31%	33%	32%	50%	48%

B. Strategies

From the six dyads in this study, the researchers have identified eight strategies for assembly and problem-solving during the task:

- Definition of a coordinate system: definition of an XYZ coordinate system in order to facilitate assembly;
- Geometrical analogy: use of geometrical shapes to describe the position of pieces (such as square or triangle);
- Object analogy: use of natural or manmade structures to describe the position of pieces (such as roof, floor, or ramp);
- Setting reference points: definition of a shared reference point from which the placement of a piece can be described (e.g., in front of, back, top). Can be another piece previously placed in the model, the receiver, or the physical surrounding space (such as the wall at the back of the table);
- Anticipated Instructions: used by the communicator to assure the receiver is aware of future placement of pieces;
- Checking: used at the request of either party for the receiver to describe the pieces assembled in the physical model in order to discover misplacements;
- Clarification: used by either receiver or communicator to ask for more definition about instructions, or to further explain their train of thought;
- Repeated Instructions: used by either communicator or receiver when trying to explain instructions or piece placement, regardless of the other party's understanding of that instruction.

The last four strategies were exclusively used during the problem-solving stage of the task after a communication breakdown happened. A breakdown of usage of these problem-solving strategies per dyad can be seen in table 2 and a description of each of the six dyads' approaches are provided in the next subsection.

TABLE II. PROBLEM SOLVING STRATEGIES PER GROUP

	Dyads						
	D1	***D2***	***D3***	***D4***	***D5***	***D6***	***Total***
Anticipated instructions	1	0	0	0	0	0	1
Axis	0	0	0	0	4	2	6
Checking	2	4	4	4	6	7	27
Clarifications	2	8	7	4	14	8	43
Metaphor Geometrical	0	2	0	0	3	0	5
Metaphor Objects	1	2	0	1	2	2	8
Repeated Instructions	0	0	0	0	6	0	6
Setting reference points	0	2	0	0	0	2	4
Total	6	18	11	9	35	21	100

C. *Dyads*

1) Dyad 1: This dyad was successful in assembling the model (see Fig. 3), and used only 371 seconds of the 750 seconds available during the task.

D1 setup: During the three minutes prior to the task, the researcher observed both participants discussing a naming convention for each block shape as well as developing a strategy for assembly. During this set-up time, the receiver organized all 100 pieces by color.

D1 Assembly process: As soon as D1 started the task, the communicator used their common representation to establish a frame of reference and initial location for parts: "I'm going to start with what I'm going to call the back." The receiver followed the instruction by manually placing his hand at the back side of the assembly space. This is consistent with what both participants discussed during the pre-task. As the receiver placed pieces in the model, he consistently asked the communicator for feedback.

This group only experienced four communication breakdowns and used four different strategies to recover from their misunderstandings, as described in Table 2.

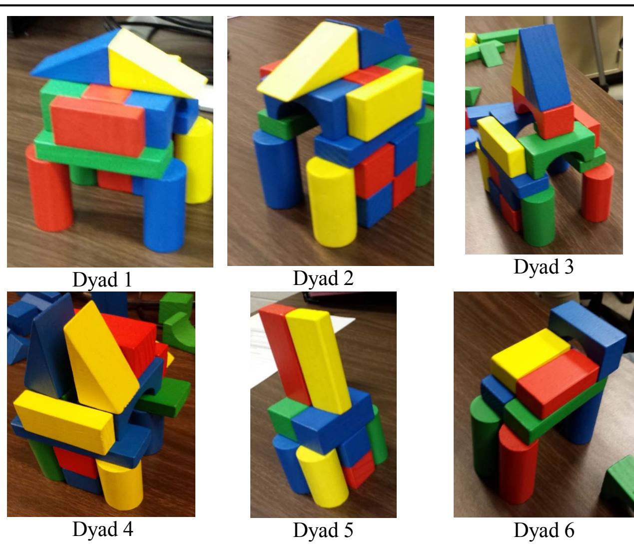

Fig. 3. Most frequently misplaced pieces (a, b)

2) Dyad 2: Dyad 2 also successfully finished the task (see Fig. 3) but used the full allocated time (750 seconds) to do so. The first and major set of misplaced pieces was a result of issues with the naming convention participants adopted during the pre-task activity, which they failed to use later in the task. The second set of misplaced pieces resulted in an immediate communication breakdown, which solved the issue. Once that issue was resolved, the dyad faced one more communication breakdown and then successfully completed the task.

D2 setup: During the pre-task, both dyad members focused on developing a shared vocabulary for the block pieces. The receiver also separated blocks according to the different block formats and placed them in front of her, but with enough space for the assembly in between the blocks and the edge of the table. They did not discuss assembly strategy as a dyad.

D2 Assembly process: The communicator in this group decided to start the task by assembling the four cylinders at the bottom of the model. The receiver did not provide any checking information regarding pieces that were being assembled; however, the receiver asked for constant clarification on instructions being given.

Participants experienced few breakdowns in communication due to unclear instructions before the receiver placed three blocks of incorrect shape in the model at approximately 150 seconds. Eighty seconds later, the receiver perceived that something was wrong with their model. In order to solve this issue, the communicator provided the receiver with an object analogy—"So you drive the car down into your lap"—to illustrate the position of the triangular blocks on top of the bridge pieces. Yet, this strategy did not seem to help the receiver, who continued to prompt the communicator for more clarification on the instructions and appeared to get frustrated. It was only another 80 seconds later that the receiver decided to approach the problem using checking and then found the misplaced pieces.

This dyad finished placing the last correct piece in the model at approximately 700 seconds. After that, participants decided to review the model and start a checking procedure, which was interrupted at the 750 seconds by the end-of-task alarm.

D2 faced nine episodes of breakdown, followed by a problem-solving mode of interaction. Problem solving strategies used by D2 were varied and are shown in Table 2.

3) Dyad 3: D3 was one of the three (the others were D1 and D4) dyads to announce to the researcher that they had successfully completed the task under the designated time. However, their final model was incorrect (see Fig. 3). The placement of the 'bridge' pieces (problem 'a') presented a challenge to the dyad. Also, D3 placed the top two pieces in a vertical position, as opposed to the correct horizontal position.

D3 setup: During the pre-task, this dyad focused exclusively on defining a shared vocabulary, which was similar to D2's strategy. D3 did not attempt to develop an assembly strategy. During the pre-task, the receiver separated one block from each different block shape available, except one of the triangular pieces, and placed them in front of the assembly area. Participants did not notice that there was also a second triangular shaped piece available. This caused a communication breakdown towards the end of the task.

D3 Assembly process: At the start of the assembly task, the communicator seemed confident; however, the receiver seemed hesitant when asking for more clarification. D3 started to assemble the model using the four cylindrical pieces, after which the receiver asked the communicator to slow down when giving instructions. D3 reached their first breakdown in communication at 92 seconds, when the receiver placed the cube pieces on top of the cylindrical pieces, instead of in between them (see Fig. 1 for target model). The source of this problem relates to the failure to recognize the multiple geometric features of the cube pieces, resulting in a different interpretation by the receiver.

Shortly after fixing the issue with the cube pieces, the communicator wrongfully indicated a rectangular piece over the blue and yellow cylinders. This mistake drove both participants to a communication breakdown at approximately 260 seconds into the task, when the receiver could no longer place the pieces properly into the model. The receiver noted at the 322 second mark: "R3: *Wait… Is this right? I'm not sure*" and started to check the model for inaccuracies. It was only later, at 409 seconds, that both members agreed that something was missing from the model; at this point they did a thorough checking of the model and the problem was discovered.

Members of this dyad seemed to become more comfortable working together towards the end of the task. They were less interactive than dyads 1 and 2 (see Table 1) and faced eight communication breakdowns; however, D3 only employed two problem-solving strategies, as seen in Table 2.

4) Dyad 4: D4 was the last of three (the others were D1 and D3) dyads to announce to the researcher that they had successfully completed the task under the designated time (they finished at 640 seconds). Similar to D3, their final model was incorrect (see Fig. 3). The placement of the 'bridge' pieces (problem 'a') presented a challenge to the dyad, and the rotation of the triangular pieces on top of the model also presented a challenge.

D4 setup: During the three-minute pre-task, D4 also focused on developing a shared vocabulary for the block pieces. They did not cover assembly strategies during the pre-task, and just as time finished in the task, the receiver realized that they had forgotten to name one of the pieces – a semi-circle shape that would not be used in the task. This communicator also sorted out the wooden blocks by color prior to the beginning of the task.

D4 Assembly process: This dyad had its first misplaced piece in the model at the 12 second mark, due to the communicator not conveying the position of each cylinder-shaped piece that forms the base of the model. The receiver did not question this lack of instruction and placed the green cylinder adjacent to the yellow and the blue cylinders. When trying to place a 'bridge' piece from blue to yellow, the only solution was to use a diagonal across the model. The model became highly unstable.

Participants did not check for possible previously misplaced pieces, therefore they continued having communication issues in between assembling new pieces. At the six minute and one second mark, due to the unstable nature of the physical model, all but the four cylinder pieces fell down. While reassembling the model, the receiver realized the position of the 'bridge' piece before was inaccurate, asked the communicator for more information, and then correctly assembled the pieces.

The next set of misplaced pieces occurred shortly afterward, at the 336 second mark. The receiver did not appear to understand the proposition "in between" in the way it was intended by the communicator, and placed the red 'arch' piece on top of the blue and green arches. This corresponded to 'problem a' mentioned previously in this paper. D4 was not able to detect this problem during assembly. Then, D4 failed to place the triangular-shaped pieces on top of the model correctly. The communicator and receiver seemed to have difficulties making themselves understood to each other as to how the triangular pieces are displayed at the top of the model.

The communicator seemed hesitant when conveying information about these triangular pieces. In response, the receiver indicated that they did not understand: "No… Can you repeat it again, please?" The receiver tried to explain it differently. However, the result still was incorrectly represented in the model.

Finally, D4 faced another breakdown related to placing the cube pieces between the cylinders in the model. Again, though problem solving strategies were used, these pieces were placed incorrectly in the model.

This dyad only had five communication breakdowns and used only three different strategies during their problem-solving mode, as indicated in Table 2.

5) Dyad 5: Dyad 5 was the first to not complete the task during the 750 seconds. Both the communicator and receiver displayed signs of frustration at some point during the exercise, even though both members were highly communicative. Participants of this dyad were unable to place the 'bridge' pieces, presented as 'problem a' in figure 2. The rectangular pieces on top of the model in their final model (see Fig. 3) show how the receiver misunderstood the placement of pieces in 'problem b'. This group faced the most communication breakdowns of all the dyads, with a total of 15 breakdowns. The duration of the breakdowns varied, and after the first piece was misplaced in the model at 91 seconds, D5 was unable to correct the model for the remainder of the task. This means that after 91 seconds, this dyad was working with an inaccurate representation of the model.

D5 setup: During the pre-task, both participants chose to define a common vocabulary for the pieces, and the receiver mentioned the need to establish an axis system (with x, y, and z coordinates) for them to work with. However, it seems that the communicator did not pay full attention to this convention because, during the task, this participant seemed to have forgotten the established coordinates, as observed in the following verbal exchanges.

D5 assembly process: Most of the issues started due to the communicator wrongfully indicating the rectangular pieces below the one indicated as problem 'b' as 'cuboids', at approximately 89 seconds. The receiver placed the piece according to their pre-task naming convention, although he questioned this instruction given by the communicator, who confirmed the use of cuboids.

D5 was not able to correct this piece, and participants continued on in assembly mode. The next set of pieces assembled were the four square pieces in between the green and yellow cylinders. Again, the receiver could not successfully understand the placement of the pieces because of an ambiguous instruction: "And the other side blue". While the communicator was still referring to the same cylinders, the receiver assumed the instruction was to build a similar two cube system between the red and blue cylinders. This dyad did not employ checking as a problem solving event at this point during the task.

Also, during the duration of the task, the communicator forgot about, or chose not to utilize, the coordinate system both participants had talked about using during the pre-task. The receiver asked the communicator for xyz coordinates seven times during the duration of the task, but only once did the communicator respond to the receiver's requests. Noting that the axis approach was not helpful to the progress of the task, the receiver then used analogies to create a common language with the communicator. Again, the communicator did not express the same language, which confused the receiver. This situation contributed to the escalation of frustration for both participants.

Given D5's lack of success as time progressed during the task, and in order to develop a shared language with the receiver, the communicator attempted to use an analogy about the letter 'T' at the 604 second mark. This was used as a way to describe the placement of problem 'b' (see Fig. 1) in relation to the piece below it and to correct some of the issues. Again, this cue was not clear for the receiver, who was unable to correctly place more pieces into the model.

As mentioned previously, this dyad had the most communication breakdowns (15), they were also the dyad that used the greatest number of different problem solving strategies, even though some of those strategies, such as analogies and repeated instructions, proved unproductive in achieving the target. Problem solving strategies used by the dyad D5 members are described in Table 2.

6) Dyad 6: Dyad six did not complete the assembly in the specified time and also had incorrect pieces in the model by the 750-second time limit (see Fig. 3). The dyad was very successful during the initial half of the assembly task until one piece was misplaced in the model. From that point on they were in a cycle of communication breakdowns and problem solving. This cycle resulted in the receiver adding and removing pieces without making any progress. Eventually the dyad had multiple erroneously placed pieces. D6 could not make any additional progress beyond their initial state and ended the task with only six of the seventeen pieces correctly placed. These pieces represent the initial stage of their problem solving; they could never back track their process to this point.

D6 setup: During the pre-task, similar to the other dyads, both participants discussed naming conventions but did not identify any assembling strategies. The receiver did not organize the blocks in any clear manner before beginning the task or define a frame of reference.

D6 assembly process: D6 started the task by placing all four cylinders at the base of the model. The communicator used the receiver as the point of reference for the placement of the pieces, then moved to the blue cylinder as the reference point. As time went on, issues with placement of pieces increased, and the need for a shared reference system (using an axis reference) was mentioned by the communicator at the 238 second mark.

The use of the axis system seemed to help the receiver deal with instructions for some seconds; however, this was not effective when dealing with problem 'b', which this dyad had extreme difficulty negotiating. At 328 seconds, when participants were misunderstanding each other, the receiver decided to use a checking strategy to verify reasons as to why they could not reach a shared understanding. Again, the communicator tried the axis approach, but this explanation was unsuccessful and no advancements in placing pieces were made. Much of the discussion between communicator and receiver was aimed at describing the placement and rotation of the two smaller rectangular pieces presented in 'problem b'. This consumed the greater portion of the problem solving mode of D6. Location words such as 'adjacent', 'parallel', and 'next to' were ambiguous for the receiver, as there was not a clear reference point.

Towards the end of the task, at the 724 second mark, there was a clear disconnect between receiver and communicator. While the receiver was explaining to the communicator their inability to place more bridges in the model, the communicator continued with instructions regarding new pieces to be added.

This group presented the lowest number of iterations (181) and ten communication breakdowns. The communicator of this dyad seemed confident, and usually took time in analyzing and describing the model. On the other hand, the receiver seemed anxious and several times asked the communicator to provide the next set of instructions: "Okay, next. Keep going."

V. Discussion

Communicating spatial information requires participants to negotiate a shared model of a system and a systematic approach to the assembly and problem solving process. The authors anticipated that the dyads would be challenged when managing the multiple dimensions of the virtual model. Each component of the model had dimensions of length, width, height, shape, and color, plus relative location and orientation to each other and within a larger space. The authors were interested in identifying how successful and unsuccessful dyads noticed these dimensions and developed a process to manage their communication of these dimensions. Several communication patterns emerged from the data, including the need for 1) initial planning, 2) monitoring instructions, and 3) detecting and correcting errors quickly. These key attributes of metacognition associated with effective problem-solving strategies reveal factors engineering and technology students need to know as part of their communication skills.

Planning, monitoring, adapting strategies, and correcting issues are important metacognitive skills and strategies necessary for the successful implementation of a task [5, 6]. Previous research has shown that novices and experts may face difficulties in strategizing a task, either by refusing to change strategies or by relying on trial and error [10, 11]. During the task, the present authors saw these patterns within one or multiple dyads. Frustration caused by communication issues could have influenced results; however, more research should be done to evaluate this premise.

Students also had difficulties recognizing unclear or ambiguous information during the task, resulting in many misplaced pieces and communication breakdowns. Researchers of shared mental models have studied communication patterns and indicated the importance of information quality and feedback to the success of a task [23]. This also confirms the importance of communication during spatial tasks, as found by previous research [27].

Finally, checking was used mostly as a problem-solving strategy after a communication breakdown had occurred or pieces was misplaced in the model. Except for Dyad 1, none of the dyads relied on checking as an essential strategy during assembly mode. Monitoring the task is an important metacognitive skill, and the present study suggests that students recognize the value of monitoring or screening the model for error as a corrective and not as a preventive measure. Previous research [5, 6, 9] indicates that teaching metacognitive strategies to students is possible and desirable, and we believe STEM students could benefit from training in metacognitive strategies as a way to improve their communication skills during spatial assembly tasks.

VI. Limitations

Some important limitations apply to this study and must be taken into consideration while interpreting the results obtained, such as the limited sample size of twelve participants, grouped into six dyads. For a qualitative study like this one, we would have preferred 10-15 dyads, which typically is enough to lead to saturation of codes. Also, this study did not control for personal characteristics of the participants, such as: language barriers for those students whose first language was not English; peer relationships prior to the task; peer personalities; professional experiences; academic progress; and differences in spatial ability. Each of these factors may influence the extent to which we can generalize these results to other learners, who may have unique needs as part of a training activity.

VII. Conclusion and Further Research

In this paper, researchers have analyzed how dyads of technology graduate students communicated spatial information during an assembly task. Researchers were especially interested in how students dealt with difficulties, especially which strategies they used to detect miscommunications and how they recovered from those miscommunications. This quasi-experiment was performed on six dyads, and results indicate that most problem solving and assembling strategies were similar between the dyads. Strategies specific to the problem solving phase include asking for clarification, checking, and repeating previous instructions. Of these three, repeating previous instructions added frustration to the dyads that used it. Checking of previously assembled pieces was used as the second most used problem solving strategy but was not performed during assembly mode as a monitoring task. In addition, using analogies helped students to deal with certain spatial information during the task. However, in the cases in which analogies were unclear or could be understood in more than one way, they caused more confusion between receiver and communicator.

Results of the present study suggest that students could benefit from instruction that helped them monitor for ambiguity in language. This would benefit students when receiving instructions and also would improve their own communication skills when giving instructions to others, especially regarding spatial information. One potential training method would be to help students become aware of the importance of key dimensions of spatial information and the relationship of these dimensions within a frame of reference. The instruction could help train them to notice these features and become aware when their own statements about models are potentially ambiguous; it could help them identify when their frame of reference is different from their partner's.

Both effective communication skills and teamwork are seen as essential student outcomes by reference [2], which indicates an awareness of the importance of these skills for technology and engineering education. Therefore, teaching these skills early in a college student's academic career could be a valuable instructional goal.

Further studies are needed to verify the influence of spatial ability in recognizing spatial information ambiguity, study how to use metacognitive skills to monitor ambiguous spatial information, and develop strategies to help students communicate spatial information effectively.

References

[1] J. Wai, D. Lubinski, and C. P. Benbow. "Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance." Journal of Educational Psychology 101, 2009, p.817.

[2] Accreditation Board for Engineering and Technology (ABET). Criteria for Accrediting Engineering Technology Programs. Baltimore, MD: ABET, 2016.

[3] E. WL Cheng, H. Li, P. ED Love, and Z. Irani. "An e-business model to support supply chain activities in construction." Logistics information management 14, no. 1/2, 2001, pp. 68-78.

[4] Bellanca, James A., ed. 21st Century Skills. Bloomington: Solution Tree Press, 2010. Accessed June 12, 2017. ProQuest Ebook Central.

[5] M. Perry, and D. Sanderson. "Coordinating joint design work: the role of communication and artifacts." Design studies 19, no. 3, 1998, pp. 273-288.

[6] A. L. Brown, "Knowing when, where, and how to remember: A problem of metacognition." 1978, pp. 77-165.

[7] J. H. Flavell. "Metacognitive aspects of problem solving." The nature of intelligence 12, 1976, pp. 231-235.

[8] T. Iiskala, M. Vauras, E. Lehtinen, and P. Salonen. "Socially shared metacognition of dyads of pupils in collaborative mathematical problem-solving processes." Learning and instruction 21, no. 3, 2011, pp. 379-393.

[9] N. J. Anderson, Neil J. "The Role of Metacognition in Second Language Teaching and Learning." ERIC Digest, 2002.

[10] B. Blummer, Barbara, and J. M. Kenton. "Improving student information search: A metacognitive approach." Chandos Publishing, 2014.

[11] P. A. Frensch, and R. J. Sternberg. "Expertise and intelligent thinking: When is it worse to know better." Advances in the psychology of human intelligence 5, 1989, pp. 157-188.

[12] D. Tabatabai, and B. M. Shore. "How experts and novices search the Web." Library & information science research 27, no. 2, 2005, pp. 222-248.

[13] A. K. Erbas, and S. Okur. "Researching students' strategies, episodes, and metacognitions in mathematical problem solving." Quality & Quantity 46, no. 1, 2012, pp. 89-102.

[14] G. Klein, R. Pliske, B. Crandall, and D. D. Woods. "Problem detection." Cognition, Technology & Work 7, no. 1, 2005, pp. 14-28.

[15] J. E. Mathieu, T. S. Heffner, G. F. Goodwin, E. Salas, and J. A. Cannon-Bowers. "The influence of shared mental models on team process and performance." Journal of applied psychology 85, no. 2, 2000, pp. 273.

[16] P. N. Johnson-Laird, P. "Mental models and human reasoning." Proceedings of the National Academy of Sciences 107, no. 43, 2010, pp.18243-18250.

[17] R. Klimoski, Richard, and S. Mohammed. "Team mental model: Construct or metaphor?" Journal of management 20, no. 2, 1994, pp. 403-437.

[18] P. N. Johnson-Laird, Philip Nicholas, and R. MJ Byrne. Deduction. Lawrence Erlbaum Associates, Inc, 1991.

[19] J. A. Cannon-Bowers, E. Salas, and S. Converse. Shared mental models in expert team decision making. In: J. Castellan Jr. (Ed.), Individual and group decision making: Current issues Hillsdale, New Jersey: Lawrence Erlbaum Associates, Publishers, 1993, pp. 221–246.

[20] W. G. Chase, and H. A. Simon. Perception in chess. Cognitive psychology, 4(1), 1973, pp. 55-81.

[21] J. Langan-Fox, A. Wirth, S. Code, Langfield-Smith, and A. Wirth. "Analyzing shared and team mental models." International journal of industrial ergonomics 28, no. 2, 2001, pp. 99-112.

[22] M. T. Maynard, and L. L. Gilson. "The role of shared mental model development in understanding virtual team effectiveness." Group & Organization Management 39, no. 1, 2014, pp. 3-32.

[23] P. C. Rasker, W. M. Post, and J. M. C. Schraagen. "Effects of two types of intra-team feedback on developing a shared mental model in Command & Control teams." Ergonomics 43, no. 8, 2000, pp. 1167-1189.

[24] A. T. Denzau, and D. C. North. "Shared mental models: ideologies and institutions." Kyklos 47, no. 1, 1994, pp. 3-31.

[25] Y.-C. Hsu. The effects of metaphors on novice and expert learners' performance and mental-model development. Interacting with Computers, 18, 2006, pp. 770–792.

[26] M. L. Gick. Problem-solving strategies. Educational psychologist, 21 (1-2), 1986, pp. 99-120.

[27] S. P. Brophy, and D. L. Schwartz. "Interactive analogies." In Proceedings of the International Conference of the Learning Sciences, 1998, pp. 56-62.

[28] W.-T. Fu, L. D'Andrea, and S. Bertel. "Effects of Communication Methods on Communication Patterns and Performance in a Remote Spatial Orientation Task." Spatial Cognition & Computation, 13(2), 2013, pp. 150–180.

[29] J. Saldaña. The coding manual for qualitative researchers. London ; Thousand Oaks, Calif.: Sage, 2009.