Spatial Intelligence and the Research – Practice Challenge

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Abstract: Spatial intelligence is deeply related to success in the STEM disciplines (science, technology, engineering, and math) yet teachers are unaware of the concept. This paper reports on a teacher, researcher, and designer collaboration focused on translating research shown to improve spatial thinking practice. This translation is supported through a spatial "toolkit" of activities designed to raise teachers' spatial intelligence awareness and improve spatial thinking practice.

Introduction

In this paper we will describe the efforts of the Spatial Intelligence and Learning Center (SILC) to impact elementary school teachers' knowledge and incorporation of spatial content in the school day. These efforts face two interrelated sets of problems. The first is a central problem of education research: namely, how to translate research insights developed in the lab into classroom practices. The second relates to the unique nature of spatial intelligence: as a domain of research it has no named corollary in the school day, greatly exacerbating existing difficulties in bringing research to practice. Though spatial intelligence has important implications for success in the STEM disciplines (Science, Technology, Engineering, and Math), it is not itself an independent discipline. We have yet to find a school that has a class called "Spatial Knowledge"; rather, unexploited opportunities for spatial instruction are ubiquitous throughout the existing curriculum.

In the research literature models have been proposed to bridge the research/practice divide (e.g. Bryk & Gomez, 2008; Schoenfeld, 2009). These models describe a research effort that is vertically integrated and involves design collaborations between teachers and researchers. In this paper, we describe a design effort that substantially follows these approaches, but is modified to accommodate a domain in which the desired content is entirely unknown to teachers, and does not exist in the school curriculum. We do so by way of a spatial "toolkit" of activities, an innovation tailored to the unique circumstances of spatial intelligence research, by allowing teachers the flexibility to incorporate spatial elements in their curricula, without focusing on one specific domain.

Spatial Intelligence in the Classroom

A central hypothesis of SILC is that particular experiences that occur early in life are important in laying the groundwork for spatial development. However, unlike other domains, notably language and literacy development, we currently know little about the preconditions for the development of robust spatial skills. SILC researchers have addressed this question through a number of studies examining the development of spatial language, engagement in spatial activities, and the relation of individual variations in these areas to the development of spatial skills themselves, along with a variety of domains of academic achievement.

Recent findings have shown that individuals who are more advanced spatial thinkers are more likely to major in STEM disciplines in college and to choose STEM career paths, even controlling for verbal and mathematical achievement levels (e.g. Hedges & Chung, 2008; Shea, Lubinski, & Benbow, 2001). Correlations specifically between visual-spatial ability and initial mathematical skills are even apparent as early as preschool (Robinson et al., 1996) and relate to middle and high school math achievement (Wolfgang, Stannard, & Jones, 2001). These relationships are not surprising, as spatial reasoning is central to many domains, not only explicitly in fields such as geometry, algebra, and calculus, but also as a foundational component in many domains (e.g., spatial reasoning is required for the construction of the nonverbal mental models that may underlie early arithmetical thinking and is critical to the ability to understand and create the physical models, diagrams, and visualizations used in fields such as science and engineering).

This reality highlights the importance of understanding the development of spatial thinking and its support. While it was long believed that spatial reasoning ability is biologically fixed, there is mounting evidence that training enhances spatial performance (Baenninger & Newcombe, 1989; Huttenlocher, Levine, & Vevea, 1998). Given this context, we would like to understand how the classroom environment and school content contributes to spatial reasoning, and perhaps more importantly, whether we can translate the rich spatial intelligence data we gather in the lab to classroom settings. Doing so would allow us to modify the classroom environment to enrich spatial input, which may enhance the spatial capacities of all students, and might perhaps provide particular benefit for those students who enter school with deficits in spatial reasoning.

Initial Pilot Work: Identifying a Problem

That we need to modify the existing classroom context to enrich spatial input was made clear in an early pilot study. In this work we explored the spatial environment of a cohort of eight teachers' classrooms in an elite private elementary school. We began by cataloguing the representations found on the walls of the classrooms, as representations have the potential to contain a great deal of spatial information, such as the information contained in graphs, charts, maps, and measurement tools (e.g. rulers and thermometers, as in Figure 1). Because representations represent content visually and include explicit spatialization of data, they constitute an obvious opening for teachers to target spatial abilities, yet our pilot study demonstrates this is rarely the case.

Each classroom was photographed, and the representations were entered into a database where they were organized by representation type, subject area, and spatial content, among other factors.

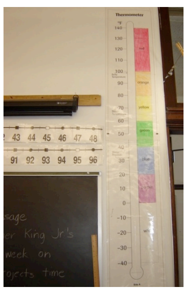


Figure 1. Thermometer Representation

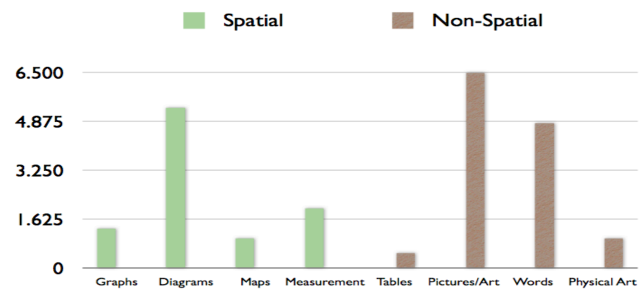


Figure 2. Average Number of Representations Per Classroom

Overall, there were more non-spatial representations than spatial representations (with an average of 12.9 per class to 9.7). As represented in Figure 2, diagrams constituted the only category of spatial representation frequently seen in classrooms. The majority of representations were decorative, displays of student work, or classroom guidelines, and very few required the use of spatial thinking (such as mental rotation, scaling, orientation, alignment, etc.), as even the diagrams (which do represent information spatially) did not make large spatial demands on students.

We followed up the representation catalogue by conducting clinical interviews with teachers in these classes. We tried to assess the degree to which they were aware of spatial intelligence and the degree to which they incorporated spatial elements in their classroom activities. For example, we gave teachers a sorting task, presenting them with more than 40 different pictures of real classroom representations. Teachers were asked to choose which of the assortment they would put on their classroom walls. We asked them to describe their decision-making process and to think about how they would utilize the representations. The following teacher's opening remarks as she sorted were typical of the responses we received:

> As I'm looking I'm sorting into what different programs require as resources for curriculum – that would be one pile. And included in those resources would be some things that implement our program… I would want to include things from different academic areas.
> I also think its really important to include children's work on display, some of these are hints about what to do when you're stuck… how to be prepared for school, I think it's important to have tips for kids, I also think in many of the classrooms there are class rules that have been generated by the class—those I like to post.

Over the course of the interview we pressed teachers to talk about representations that had explicit spatial content, such as the more spatially demanding charts and diagrams, and even in those cases teachers did not discuss spatial thinking. When asked to provide rationales for rejecting representations in their classes, teachers mostly cited aesthetics and the explicit relationship of the material to current curricular content (e.g. "too cutesy" or "low applicability to my class"). Thus, our pilot study demonstrated that even with respect to representations, which represent content visually, and often incorporate explicit spatialization of content, the teachers in our study rarely considered spatial elements or opportunities for spatial instruction within the existing curriculum.

Translating Lab Research

In the lab, researchers have had numerous insights into spatial learning, which, if translated to the classroom, could have an impact on students' spatial thinking. The problem, however, is that one cannot unproblematically translate lab research to the classroom. Even if we assume that our lab studies produce real insight that is relevant to classroom instruction, we must still struggle with the translation of that insight into something that has educational utility, a recognition that helped motivate the early development of design research (Brown, 1992). This is a problem that has been well articulated in the literature, as researchers have noted that laboratories are radically different environments than classrooms. In laboratory environments there is one-on-one interaction, with no outside noise or distraction, the intervention is heavily scripted so that experiments can be replicated, and the intervention is not embedded in any curricular context. Furthermore teachers are not researchers. Researchers develop deep expertise on very narrow problems, giving them the ability to devote time and energy to relatively small parts of the curriculum – a luxury teachers do not have. Often, teachers to not understand the interventions, or are unwilling to make changes to their practices, and in many cases they are deeply constrained by state, district, or school regulations.

A second set of problems is that, unlike other collaborative design projects, we needed to introduce teachers to entirely new concepts regarding intelligence, while having no pre-existing coherent curriculum to manipulate, improve, or change within the school curriculum. Improving and engaging students' spatial reasoning is important for a wide range of school content and skills, but it is not itself a learning domain; rather, it is an underutilized cognitive ability. Moreover, our pilot work indicated that teachers were entirely unaware of spatial intelligence as a concept. This challenge magnifies and makes more intractable some of the existing challenges to moving lab research into the classroom. The problem of acontextuality becomes much more profound when the lab studies do not concern themselves with school content, but with, for example, spatial alignment, and the problems of teacher impact become much more difficult, as well. Teachers do not have a baseline understanding of what spatial intelligence is, the way they do with content areas such as math, science, and reading. While it is true that many educational innovations are previously unknown to teachers, here we are not restructuring practices, reorganizing content, or devising new methods, but in essence raising awareness of an entirely new domain of intelligence, and asking teachers to act on that awareness.

To understand how these problems are magnified by the lack of content domain let us contrast them with substantial inquiry learning efforts. Early research, much of it based on lab studies, indicated that the deepest and most powerful learning takes place in context, and that acontextual learning was weaker and less meaningful. This insight (much simplified here) has led to a spate of programs to build curricula organized around meaningful activities, and more authentic organization of content. However while such programs may require pulling content from different areas of the traditional curriculum in order to organize that content along particular design principles, the basic content itself remains familiar. With spatial intelligence, however, there is no content that can be pulled from one place and reorganized; rather, many different content areas need to be taught with more and different information attached, and in some cases, in different ways.

Overcoming the research – practice gap

In recent years, the literature has once again addressed the problem of the research-practice gap, and a growing body of literature has put forth a model of research to practice that addresses many of our first set of problems. This literature comes in response, however, to a different set of problems, posed by policy dictates that prioritize large randomized trials of educational interventions, and push for an understanding of "what works" in education.

In response to these mandates, a number of researchers (e.g. Bryk & Gomez, 2008; Burkhardt & Schoenfeld, 2003; Schoenfeld, 2009) have argued that in order for research to impact practice coherent institutions need to be developed that support multiple phases of development, from early trial research to broader testing, and finally to large controlled studies. They have pointed out that in other well-established fields a significant amount of research and development takes place well before any randomized trials begin, and that any randomized test of an intervention needs to be built on a solid theoretical base. In this literature design research is identified as an exemplar of the type of initial research that can help build theory, identify both *what* works and *why* it works, and can begin to flesh out the conditions under which interventions succeed and fail in practice. Accounts of this type share many similarities. They call for a vertical integration of the research effort, so that there is real coordination between the research and practice, a less fragmented infrastructure for research and development, with significant funds directed at the early, theory building stages, and a variety of research to practice models that begin with the iterative development of working prototypes and end with wide scale adoption and testing.

These models of a unified research effort that moves from existence proofs and design testing to widespread scaled-up interventions in schools also address the major problems with translating lab research to the classroom articulated above. Iterative, collaborative efforts between designers, teachers, and researchers are ideal for producing classroom interventions that work, as these collaborations, with focused effort, can overcome the gap between the lab and classroom, moving incrementally from one-on-one, scripted, a-contextual, researcher lead studies to dynamic classroom activities. This is necessarily an incremental process because the translation is so complex; it is rare that an intervention will be successfully translated in one session. Instead, multiple iterations take place, with teachers involved in the design and analysis, allowing the entire group to adjust to teacher difficulties, district mandates, and any other obstacles that may present themselves.

In our preliminary effort to move some of our spatial intelligence insights to the classroom, we envisioned a research to practice pipeline built on strong collaborations with researchers, designers, and teachers, much like the models described above. However, our second set of problems, that is, the unique constraints arising from the lack of target domain in the school day, and the total lack of teacher awareness of the concept of spatial thinking, forced us to modify the design effort to accommodate the special nature of the domain. In the next section we describe our design process, and how that design provided a flexible solution to these constraints.

Resolving the curriculum gap: the spatial "toolkit"

To resolve these problems we adopted an approach that utilized the major collaborative features of an integrated research effort, while deliberately maintaining a broad flexibility that allowed us to work within existing school curricula and activities. Putnam and Borko (2000) describe two teacher support efforts, the SummerMath program and the CGI project, which combined intensive summer workshops with the support and involvement of researchers throughout the school year. Importantly for us, these projects were intended to change teachers' conceptions as well as their practices. Along those lines, we designed a summer work circle, bringing together nine lower-elementary public school teachers along with SILC researchers for intensive learning and design sessions, followed that up with sessions and support throughout the school year, and repeated the process again the next year, with 4 original teachers and 10 additional teachers. The nature of the support that we provided, however, was tailored to the nature of the material we were working with, and primarily took the form of a spatial "toolkit".

In an influential article on culture, Ann Swidler (1986) argued for two models of cultural impact, active in different historical circumstances. In one model culture provides a unified system that directs and orient behavior, and in another culture simply shapes a repertoire of tools, "habits, skills, and styles", which impact action indirectly, as people pick and choose from the toolkit in ways that may be fragmented and sometimes even contradictory. The notion of toolkit of resources has been adopted to talk about resources for organizational routines (Spillane, Gomez, & Mesler, 2009), as people select from available organizational resources to create strategies for action. This notion had great appeal for us. Traditional models of change, which implicitly assume a unified conception that is introduced to teachers, cannot function when there is no place in the school day or curriculum to direct action. Instead, we felt that we could work with the teachers to create an actual, literal, toolkit of practices and activities that draw on the insights we have developed in the lab, but are flexible enough to accompany teachers existing curricula. By working with the teachers on a toolkit we felt that we would be able to increase teacher awareness of spatial intelligence and its role in the classroom, and to help teachers design spatially rich activities to compliment their existing curricula.

Over the course of the first work circle in the summer of 2008 teachers and researchers co-produced the first iteration of a spatial toolkit. In this toolkit, teachers utilized the knowledge that they acquired in research presentations and applied it to their curricula, merging their expertise with that of the researchers. The teachers had free range to develop spatially rich projects on any aspect of the curriculum and classroom experience. For example, one pair of teachers developed a community mapping activity where the students built a map of their community, starting with the school at the center, and moving outward to the students' houses and other local landmarks, while another pair of teachers developed a technique for representing the daily schedule using spatial representations that were proportional to the length of time for each component of the schedule.

In order to understand how teachers were implementing toolkit items generally, during the year we maintained contact with the teachers, as they filled out a daily checklist of their use of spatial representations and activities, and reported back to us on their use of the initial items in the toolkit. We found that of the representations that teachers indicated that they used, 72 percent were used in an explicitly spatial way.

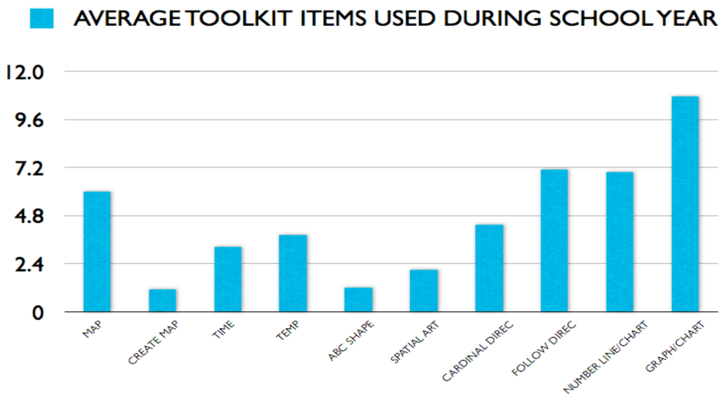


Figure 2: Distribution of Toolkit Items Used

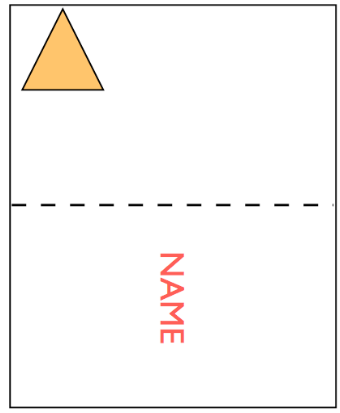


Figure 2a. Following Directions Example

We found that a domain did not need to be explicitly spatial for teachers to begin to incorporate explicitly spatial elements. One of the most frequently used toolkit items (Figures 2 and 2a, above) was an exercise that teachers use in the earliest grades to help students learn to follow directions. This activity could be done in any number of ways, but many teachers saw it as a perfect place for students to follow specifically spatial directions, such as folding a paper horizontally, putting a triangle in the top left corner, and writing their names perpendicular to the fold.

We also observed classes where the toolkit activities were being conducted. At points throughout the school year we held follow-up sessions where we had the opportunity to get additional feedback from teachers on the successes or failures of the toolkit activities. At these meetings we were also able to present teachers with new activity suggestions for them to tailor to their class use, based on our observations of their classes. For example, teachers expressed interest in a variety of puzzles, and SILC research has shown that puzzle play predicts children's performance on a mental transformation task (Cannon, Levine, Huttenlocher, & Ratliff, under review). We therefore developed a series of math puzzles (see Figure 3), such as a math domino game, a number grid puzzle ("What number am I?"), and a tangram math game, for the teachers to adopt in their classrooms.

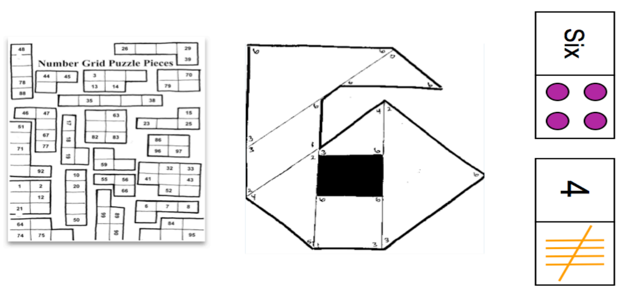


Figure 3. Math Puzzle Games

The toolkit format allowed us to modify and revise activities beyond the initial work circle, in order to accommodate teachers' needs throughout the year, and to insure that teachers were actively aware of spatial intelligence as a factor in their classrooms.

Teachers had the ability to pick and choose when and where the activities in the toolkit might be used, sometimes modifying them to fit their classroom needs. This design choice has numerous affordances particular to the material we were working with, but it also had some constraints. One constraint is that modified material sometimes changes such that the activity is no longer clearly representing the same concept as that in the lab activity. For example, a training study conducted in SILC labs (Levine, Kwon, Huttenlocher, Ratliff, & Dietz, 2009) demonstrated greatly improved ability to measure objects that are misaligned on the ruler when unit pieces are explicitly placed on the ruler (highlighting the space between hash marks as the unit, rather than the hash marks themselves), and when an item is first misaligned and then moved into alignment at the end of the ruler. In observing one 3rd grade class implementing a classroom version of this task, we noticed that the teacher had modified the activity to integrate with a number of different aspects of her curriculum. Instead of using the unit pieces to measure the spaces, and moving the measured item to the beginning of the ruler, she had the students use the units as part of a subtraction strategy, with some students putting units on all of the spaces up to the end of the item, and then removing those that did not align with the item. She explained this strategy to the students by saying "The turtle is four centimeters long because it ends at 6 and starts at 2; and 6 - 2 is 4" (Figure 4).

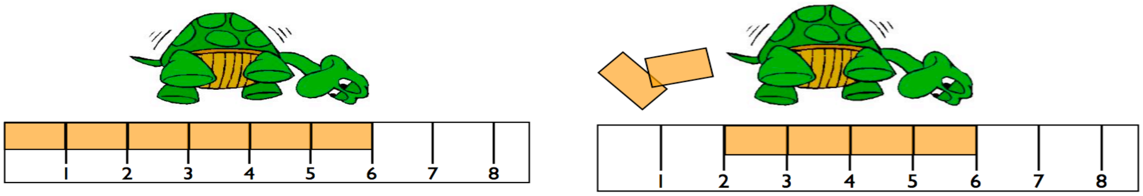
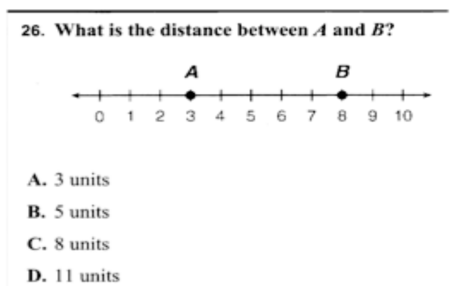


Figure 4: Classroom Adaptation of Measurement Training

This strategy seems like a good strategy for solving misaligned ruler problems, and certainly takes advantage of spatial processes such as alignment; however, it is not the strategy that we had investigated in the lab. On the other hand, when provided with a sample of the practice ISAT standardized assessment that the students take in 3rd grade, we noted that there were explicit number line questions that demanded exactly the subtraction strategy that the teacher was urging the students to utilize (Figure 5). This example highlights the sort of interplay between research and practice the toolkit approach allows.


26. What is the distance between *A* and *B*?

A B
0 1 2 3 4 5 6 7 8 9 10

A. 3 units
B. 5 units
C. 8 units
D. 11 units

Figure 5: ISAT Item Using Subtraction Strategy

Multiple types of Toolkit Impact

We believe our spatial toolkit impacts teachers precisely because it does not attempt a unified curriculum to replace an existing curriculum; it is instead a product that contains a multiplicity of resources, the sum of which can impact teachers' understandings and practices as they choose those that work for them. As we built toolkit resources together with teachers and observed their classes we were able to see five different ways in which spatial resources were integrated into classes, each of which represents some aspect of growing teacher awareness of, and interaction with, spatial intelligence in the classroom.

Coherent Independent Content: Although the toolkit as a whole does not offer a unified curriculum some activities do independently mirror content that exists in the school day and can be used as replacements. For example, using a ruler is a skill that is taught in the early grades, and, as noted above, is also reflected in the toolkit. Although some teachers modified the activity substantially, other teachers used the activity without very many changes. This is a hallmark of the toolkit approach, which allows teachers to choose how and when they will implement activities.

Reorganized Content: Much like an inquiry based curriculum will be organized around a driving question, pulling from numerous content areas in the process, some toolkit items take existing content and reorganize it around an underlying spatial concept. For example, together with teachers, we designed a series of activities that explored the use of the number line as a tool to understand the concept of unit as a basic foundation for understanding a wide range of math content, from addition and subtraction, to fractions and decimals, to area and perimeter. In the toolkit, teachers were able to utilize these activities as a coherent unit, if so they desired.

Standalone Games and Attachments: One of the great strengths of the toolkit is the presence of numerous items that are flexible and compatible with a wide range of classroom environments and opportunities for use. For example, teachers have used spatial puzzles and dominos during free time, center time, and as attachments to math lessons.

Classroom Methods: Much of the understanding that we hoped to develop in the teachers did not relate at all to particular content, but to techniques and tools that draw on spatial resources. For example, during the work circle teachers learned about research regarding the use of gesture (gesturing helps children understand spatial translation, (Ehrlich, Levine, & Goldin-Meadow, 2006)) and spatial analogies (Gentner, Levine, Dhillon, &

Poltermann, 2009). These can be used in any context in the classroom, and their use reflects a deep awareness of the utility of spatial reasoning a range of circumstances.

We observed a notable example of this in one of our second grade teachers' classes during the 2008-2009 school year. During the work circle we discussed research by Gentner that demonstrated that differences between two items are more easily discerned by students when the two items are highly aligned – that is, are highly similar, and differ only in one area. In a unit on time and clocks the teacher, unprompted by the researchers, took this concept of high alignment and applied it to the classroom to show students the correct orientation of the hands on the clock. Holding up two clocks that were supposed to represent 3:30 with nearly identical configurations, she asked them to identify what was different about the two clocks. On one clock the hands were at the six the three, and on the other clock the hands were at the six and between the three and the four (Figure 6). This was a prime example of a teacher using a high alignment spatial analogy to communicate content in the classroom.

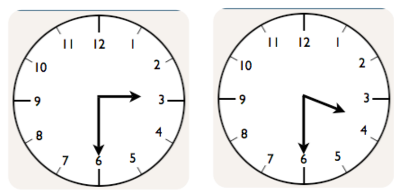


Figure 6: High Alignment of Clocks

Language: A major aspect of teacher uptake was in the use and incorporation of spatial language into the school day. This is one area that teachers immediately "got" and found ways to insert more, and more advanced, spatial language into their lessons. One teacher started using the cardinal directions when giving instructions to her students, and informed us during a feedback period that her students were no longer getting lost in the hallways of the school. Other teachers started to use more advanced terminology than they would have otherwise (for example: parallel, horizontal, diagonal, and symmetry were all mentioned by teachers).

The Toolkit Approach as a Way to Change Teacher Thinking

In putting together a spatial toolkit we have been trying to introduce the concept of spatial intelligence to teachers, and to have teachers begin incorporating their understanding of spatial intelligence into their practices. Unlike a design for a new science curriculum or a new method for teaching fractions, many of the items in the toolkit might appear trivial—puzzles, games, following directions—but they serve an important purpose, and communicate a great deal of information. Because the activities are flexible, engaging, and teacher designed, teachers' perceptions of teaching have changed to include their awareness of spatial thinking as an important element of classroom instruction. Without any radical restructuring of the curriculum or of their methodology, teachers have been thinking more subtly about spatial content as they teach, and have been organizing their teaching around this thought process.

For example, teachers responded to an evaluation survey by uniformly commenting on how much their awareness had changed over the course of the study. One typical teacher wrote, "I have become much more aware of spatial intelligence and how to incorporate these things in my classroom". Nearly every teacher had some comment on the need to think explicitly about spatial intelligence while teaching (e.g. a sample of responses to "challenges I face": Being very explicit in spatial instruction; Thinking spatially about the lessons; Being aware of what I have in my classroom that ties into spatial thinking; Using specific spatial language, etc.). These responses reflect a reality in which teachers are using the toolkit as a resource that enables them to keep spatial intelligence in mind while constructing lessons and designing activities. This represents a major first step in impacting teacher practice.

Final Thoughts

Spatial thinking is critically important for problem solving across the various sciences, as well as in many areas of daily life. Given recent evidence that spatial cognition is malleable, and hence that spatial learning can be fostered by effective technology and education (see Liu, Uttal, & Newcomb, 2008), we would naturally like to extend these findings to educational settings. The first steps in this process are making teachers aware of the existence of spatial intelligence, and impacting their practice to include activities that promote spatial reasoning.

In this study, we have tried to demonstrate some of the successes and challenges in introducing spatial intelligence to teachers and implementing change in the classroom. Because the concept is unknown to teachers, many areas that contain natural spatial learning opportunities are lost, and because spatial reasoning is not a subject taught in school we cannot easily build curricula to promote it. Many research-to-practice models encounter obstacles when there is no content in the school day matching the research in the lab. The development of the spatial toolkit helps fill in the gap, by increasing teacher awareness, and providing teachers with activities to supplement (rather than replace) their existing curricula. The toolkit approach allows teachers to pick and choose against a backdrop of resources and support, adjusting their understanding over time, and in concert with researchers.

As part of an ecology of events the toolkit can be an important early-stage product to spur the conversation between research and practice. After a number of work circle iterations we should have a good idea of what works and what doesn't, and under what circumstances different spatial activities will fit into the school day. A publishable end product could be produced and tried out more widely, giving a broader set of teachers the opportunity to build awareness of spatial reasoning through engagement in these activities. As teachers become more familiar with the concept, and more substantially adjust their teaching practices to include spatial content we can begin to test the impact of that content on students. Once we are certain that teachers "get it", in the sense of flexible integration with practice, we can explore how that translates to the students, and with that knowledge design even more targeted toolkit items to deepen student spatial ability.

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