Spatial Thinking and Communicating: A Course for First-Year University Students

Halil Erhan1, Belgacem Ben Youssef1,2, Michael Sjoerdsma3, John Dill2, Barbara Berry4, and Janet McCracken1,2
1TechOne Program, 2School of Interactive Arts & Technology, 3School of Engineering Science, and 4Learning & Instructional Development Centre
Simon Fraser University
Surrey, BC, Canada
{herhan, bbenyous, mjsjoerds, dill, bberry, Janet_McCracken}@sfu.ca

Abstract - This paper describes a course on spatial thinking and communicating designed by an interdisciplinary team and offered to first-year university students. An important goal was to introduce spatial thinking while accommodating the needs of the students from diverse backgrounds, educational goals and career pathways. Students in a first-year interdisciplinary cohort of 340 represented Mechatronics Systems Engineering, Business, Interactive Arts, Communications, and Computing Science. A major feature of the course design was an integrated laboratory, which served to amplify lecture content via practicing exercises aimed at developing their abilities to think and work spatially in 2D and 3D using tools including pencil and paper, digital and physical Lego, and a computer-aided design system. We describe our course design and team-teaching processes, realities that constrained our choices, the tools we use to assist our decision making during course design and delivery, and the structure and function of the teaching team. We also present selected student artifacts to demonstrate how students learned to think spatially. We then identify lessons-learned and revision plans.

INTRODUCTION

The role of spatial thinking and communicating in understanding and shaping our environment has been a focus in the last two decades, evidenced by efforts to characterize the nature of spatial thinking by cognitive psychologists, scientists, engineers, and designers with different foci ranging from exploring its role in learning to problem solving, to its influences on behavioral patterns. Some of the research focuses on 'learning' and 'teaching' a particular set of spatial thinking skills in different contexts; for example, geographic information management, psychology, data mining, visualization, and design [1][2][3][4][5]. We agree with the National Academies that “…spatial thinking is at the heart of many great discoveries in science, that it underpins many of the activities of the modern workforce, and that it pervades the everyday activities of modern life.” [1, p. 1].

New trends in university education are emerging as we understand human cognition and cognitive aspects of learning. In early university education, for example, academia has started to understand the importance of spatial concepts and they are becoming more emphasized, particularly for problem discovery and problem solving. The most explicit course offerings related to spatial thinking are graphical communication courses offered by engineering, architecture, and art departments [2][6][7][8]. The University of Southern California in the USA is one of the few universities offering dedicated courses in spatial thinking at the graduate level and in geographic information context [9]. However, we have yet to see a course explicitly devoted to spatial thinking particularly in the early university education. To the best of our knowledge, the Georgia Institute of Technology is one of a few institutions that introduces ‘visual reasoning’ for first-year college students [6]. We believe enhancing the ability of all students to think spatially and communicate visually will equip them with important problem solving and process skills required in addressing ever emerging new design challenges and tensions.

In this paper, we present an undergraduate course solely designed to raise awareness of and establish foundation skills for spatial thinking and communication among a diverse group of students.

We begin with a brief introduction to spatial thinking followed by a short description of the course design and delivery process. We analyze one team project to demonstrate student learning. We include some initial reflections on the course effectiveness and conclude with recommendations for revisions.

IMPORANCE OF SPATIAL THINKING

Human cognition has two basic and complimentary styles of information processing: a linear, step-by-step style that analyzes parts that make up a pattern (left hemisphere) and a spatial, relational style that synthesizes and constructs patterns (right hemisphere) [10][11]. The latter is most dramatically displayed in creative discoveries and other breakthroughs [12]. Spatial and visual skills are important in both problem solving and in developing insight into underlying phenomena [13][14].

Spatial thinking is particularly important in two basic forms of cognition: analyzing and describing what exists, such as in nature, and formulating what is needed, as in design and craft. Examples of the first are the study of planetary systems and the molecular structure of a material. The latter involves designing environments and objects, entailing complex cognitive tasks for defining and shaping parts, part-whole relationships, topological structures, and spatial interactions of the parts. The complexity and scale to which spatial thinking applies varies widely, for example from a child stacking...
wooden blocks to representing and analyzing a geographical region incorporating regional information.

Spatial thinking involves definition of space (as a frame of reference to locate spatial entities), identification of objects and their relationship to each other (parts and whole, proximity, containment, location, etc.), manifestation of spatial concepts in particular contexts (contextualization), and representations to identify and communicate about space and spatial entities (Figure 1).

![Figure 1. Components of Spatial Thinking.](image)

Representation is inseparable from thinking and communicating spatially and the main form of representation in spatial thinking is visual. For example, the blue prints of a building or schematic diagrams of a natural phenomenon visually describe objects of interest incorporating spatial elements and their representations. It is with these conceptions of spatial thinking in mind that we began our course design process.

**COURSE DESIGN AND CONTEXT**

**The TechOne Program and Students**

The Spatial Thinking and Communicating course was designed and offered as part of the TechOne [15] academic program at Simon Fraser University whose goal is to provide first-year university students with a cohort experience currently serving programs in Interactive Arts and Technology, Business Administration, Computing Science, Communications, and Mechatronics Systems Engineering. The Spatial Thinking course is one of the six core courses, from which students choose four. At the time of the first course offering, 340 out of 375 students were registered. The students have no prior university learning experience. The students in Engineering are expected to acquire a level of proficiency in some aspects of this course in order to allow them to continue seamlessly into an Engineering Science major focused on Mechatronics.

**Description and Course Goals**

This introductory course provides students with the foundational knowledge and technical skills required to envision three dimensional structures, visualize and think in three dimensions and to analyze and solve specific spatial thinking problems using a range of tools including: sketching, physical models and computer-based modeling software. The 14-week course prepares students to communicate their thinking to themselves and others and upon completion are expected to:

- Describe spatial thinking and the use of graphical representation and communication in engineering, business, art, and design.
- Visualize, examine, and interpret 3D representations and problems and proposed solutions.
- Create and manipulate 2D and 3D representations by sketching and using computer modeling software.
- Work in a team to build digital and physical models.
- Communicate spatial thinking in different (design) contexts to others.

Based on the assumption that achieving these objectives requires learning spatial thinking within a problem-solving context [1], the team designed a series of context-sensitive and practice-based learning activities that provided students opportunities to develop their confidence in spatial thinking. Activities moved from simple to complex building students' analog (sketching and physical models) and digital (computer models) representational capabilities. These are discussed in the following sections.

**Course Design Team**

The interdisciplinary course team consisted of 5 faculty, an instructional designer and graduate students. The faculty provided deep content expertise representing engineering, architecture and education. The role of the instructional designer was central to the process providing facilitation, support, and consultation on aspects of course design. Four graduate student teaching assistants (TAs) contributed to the course development. One TA in particular had considerable experience teaching engineering graphics at the college level.

This strong team worked closely together for over one year in what has been a once in a lifetime opportunity to incorporate their deep content knowledge, drawing upon their extensive years teaching engineering, product, and architectural design and integrating their research interests in spatial cognition and visual analytics.

**Design Approach and Process**

To illustrate the nature of the activities and outcomes associated with the final project, our course design approach focused on defining a coherent relationship between learning goals, learning activities and authentic assessments, yielding an engaging student experience. Beginning with a course concept map the team collectively produced a course map illustrating coherence between the course objectives, lectures and integrated lab activities and assessments. The weekly practice activities and assessments became the focal points for both teaching and learning spatial thinking.

The course development began five months prior to delivery and continued throughout course delivery over the academic term. An evolving *course map* helped the team to reflect upon and fine-tune the course in real-time (Appendix A). This was particularly useful for allowing the instructional team to reflect on the goals of the course to inform the teaching process. Adjustments and refinements were frequently made,
for instance we adjusted the assignment load over the course of the term.

The overall course structure consisted of a 1.5-hour weekly team-taught lecture, followed by weekly 3-hour labs of practice-based, hands-on learning activities. Instructors and TAs provided regular feedback to individuals and project teams. Weekly readings and a set of assignments provided the scaffolding necessary to prepare students to undertake a team-based project that integrated the fundamental elements of spatial thinking and graphical representation learned over the term. Computer modeling software (SolidWorks) was gradually introduced over the term enabling students to build confidence in those aspects of the tool necessary for the final project [16]. The course was delivered in a face-to-face format and course materials (lecture notes, video clips, and web-links to interesting examples) were distributed using the university’s Learning Management System, WebCT. The assessment strategy incorporated weekly lab assignments, mid-term and final exams, and a group-based major project.

**Contextualizing Spatial Thinking**

### Course Content

Students were introduced to the nature of spatial thinking through discussions of real-world examples and presentations on tools used in spatial thinking. This was followed by an exploration of spatial thinking concepts including identification of spatial entities (objects), mental and on-representation translation and rotation, assemblies, associations between objects, and objects and space, representation tools, and reasoning. We were particularly committed to the value of sketching in learning spatial skills. Thus, students were exposed to sketching techniques (freehand and using computer applications). Both techniques are imperative to spatial thinking as they complete the representation used in communicating ideas not only to others, but also to themselves.

Students learned basic skills in contour sketching, and in drawing straight lines, basic shapes (rectangles, circles), and curved lines. As the course progressed, more advanced concepts in visualization and spatial thinking, such as proportions, shape and geometry, coordinates, properties of points, lines, circles and arcs were introduced.

Following this introduction, a considerable portion of the course was devoted to (technical) visualization methods to control representing the complexity of spatial compositions through translating between 2D and 3D and using multi-view projections, cross-sections and axonometric projections (isometric, perspective). Details of the methods were presented in lecture sessions, along with a variety of in-lab and homework assignments and were a vital, integral component in supporting students in developing their spatial skills.

In order to include precision and accuracy in representations, spatial entities must be located in space and geometric properties (such as sizes) must be communicated. We introduced dimensioning basics. The course is also required to meet the needs of the Mechatronics program: the team used SolidWorks as the computer modeling system. Concepts of constraints, degrees of freedom, and modeling theory were introduced in the context of this tool.

### Integrated Laboratory Activities and Assignments

Our main objective in developing laboratory activities and assessment was to create opportunities for students to apply the knowledge gained in lectures. Initially students designed a two-axis gimbal mechanism using Lego Digital Designer [17]. (A gimbal is a device with rotating rings, commonly used in gyroscopes). Although students at this early point in the course had limited exposure to material regarding spatial thinking, they found the software easy to use since it was a digital form of a familiar toy. The goal was to discuss operations fundamental to spatial thinking, such as identification of objects, composition, rotation and translation, as well as static and dynamic relationships between spatial entities (Figure 2).

Students identified gimbal sub-assemblies and their relationship to each other, and represented these objects using a concept map [18]. The students then used their map to help them create a gimbal using the Lego software. The nature of Lego required that students also consider the necessary building blocks to create each sub-assembly. Building on this exercise, a second lab required students to create a gimbal using real Lego blocks (Figure 3). Although not a primary learning objective, students learned the limitations of software representations: during the transition from digital to physical, many had to adapt their designs to properly function in the real physical world.
To complete the foundation activities, the students undertook exercises designed to support communicating spatial information via free-hand sketches using techniques presented earlier (multi-view, isometric views). The Lego exercise was followed by a number of lab activities that incrementally introduced spatial thinking ideas through various multi-view and related sketching tasks.

The final six lab activities were dedicated to the course final project: building an animated mechanical toy (AMT), commonly referred to as automata [19]. Such toys consist of an articulated figure or model that is set into motion using a manual crank-based mechanism contained in a box. Students were introduced to AMTs as well as the necessary mechanisms: cranks, cams, gears, and friction drives needed to animate them, in lectures. Throughout this process, students applied their knowledge in analyzing ‘spatial’ entities, describing their understanding through sketches, developing their AMT design through various representation techniques, applying fundamental spatial thinking knowledge and skills throughout the design process.

LEARNING TO THINK SPATIALLY

The remainder of this paper illustrates the nature of the activities and outcomes associated with the final project. In this section we focus on the analysis and presentation of one student team project. To assess evidence of learning to think and communicate spatially, and to guide our analysis, we attempted to answer the following questions:

1. Did the students in this course learn to think and communicate spatially?
2. Did the final project assist students to integrate and apply the spatial thinking concepts and representational skills taught in the course?
3. What are the implications for course revisions?

Flying Fisherman: A Student Project

A team of three students completed the “Flying Fisherman” AMT. All three successfully fulfilled the course requirements (lectures, labs, individual assignments, exams) and the team was awarded an ‘A’ for their final group-project. The project was representative of those produced by the teams in the course as it was neither the best nor the worst and it demonstrated the expected learning outcomes. The project was organized into four phases, and deliverables representing each phase were examined for evidence of spatial thinking using the components listed in the assessment map (Appendix B): a sketch, a concept map, a digital exploded view of parts, a physical model, and a written paper. The phases of the final project are not discrete; the process is more like a conversation between phases, where one phase informs or provides feedback to the other. That this information flow is bidirectional, with students often returning to an earlier phase to revise their work.

Phase I – Concept map and 3D sketch of proposed AMT: The concept map (Figure 4) accurately represents the mechanical box, figure, and relationships of parts to whole, suggesting that the students in this case successfully represented their ideas for a “flying fisherman” AMT with moving parts and assemblies that could work together to form a functional project.

The sketch, on the other hand, has misleading information: the box shown in 3D does represent the mechanism accurately, although the figure is represented accurately in 2D. Although the sketch is a “close enough approximation” the students may have had difficulty representing the mechanical system in 3D. Our hypothesis at this stage is that the more accurate the representation, the more likely the digital and physical models will be accurately and successfully realized. Developing accurate sketches takes time and practice.

Phase II – Designs represented in a digital environment: Figure 5 shows the exploded view of parts proposed for the whole AMT. In moving from sketches to a digital model, students had to demonstrate size, location, and spatial properties of parts, proportion, and geometry. The digital model maps to the sketch. Initially, we required each student to model the parts, but due to time constraints and difficulty in assessment we changed it to a group requirement. As the resolution of the representations increases, students face different challenges – e.g., no real dimensions in sketches, accuracy was not an issue but once they moved to digital models dimensioning became an issue. Scale and proportions become important. Moving from digital to physical, students had the parts but now materials and their properties become important – assembly order is also a reality.
Phase III – Creating the physical model: Evidence of learning to think spatially is demonstrated by comparing how well the physical model conforms to the digital model created in SolidWorks. For instance, flat parts have been added to the cams and supports on the followers (see Figure 6). Understanding the relationship between parts with respect to physical forces was not possible in the digital model the students designed, but in building the physical model, they realized forces would act upon the pieces and impact the functionality of the mechanism; therefore, they modified the physical model. This team made good decisions in selecting materials for the construction of their model as it is still “alive” after 6 months and many demonstrations.

![Figure 5. Flying Fisherman AMT: Assembled (left) and Exploded Views of Digital Model.](image)

![Figure 6. Flying Fisherman AMT: Physical Model.](image)

Phase IV – Reflections paper on spatial thinking: A review of the written submission suggests that spatial thinking skills helped them differently in each stage of the project. In the digital environment, their spatial thinking skills did not incorporate real world factors even though part-whole relationships were established at an abstract level. The notion of degrees of freedom, dimensioning, and locating parts in the digital design were considered. In the physical environment of Phase III, spatial thinking skills helped them solve spatial problems. The following quotations come directly from the reflections of the students:

1. In regard to order of assembly: “However, in the physical model, we had to measure carefully by hand to ensure pieces would fit. Finally, having all the pieces together, we still had the problem of the flying fish gear system failing due to the tension force of the elastic”.
2. In determining the selection of materials and impact of the forces of gravity: “we wanted to keep everything light”.
3. In managing the forces discovered in moving from a digital to physical model: “we used some wire, strings and tape for some of the minor adjustments and movements”.

Lessons Learned

Analysis of the final group project suggests that course objectives were achieved by this team of students (see Appendix B). By including the 3D modeling tool (SolidWorks) the course also met the requirement that students learn modeling skills. However, learning to use this particular tool for spatial thinking comes at the cost of extra time due to its complexity. The complexity of SolidWorks was a challenge for new users and—although we focused only on necessary features—students still required considerable support and time to use the software. We observed that migrating from sketching and Lego to full-featured computer modeling, that requires more than a simple selection and snapping of parts into assemblies, is more challenging for some students. Despite concerns that this tool may not be the best choice for teaching spatial thinking, students did learn to use the basic functions to meet the curriculum requirements.

Important lessons were learned by the course team that will influence future delivery of this course. One of these is the need for high-level of expertise required from the TAs to successfully support students learning. In delivering the course to a large class-size and first time, we had a TA team meeting this requirement. However, we will need to provide more training on the modeling software and a TA guide is currently being produced that will include the laboratory exercises as well as additional evaluation rubrics to ensure consistency in grading. These are also necessary for continuity.

The team approach to design and teaching proved both challenging administratively and pedagogically. Currently students at SFU can only register officially (for grading purposes) under one instructor and teaching credit. Therefore, an overall teaching assessment for the course was not possible, at least through formal channels. From a pedagogical perspective, the challenges of a large team included a significant effort simply to coordinate and communicate. We relerned Fred Brooks’ lesson on this [20] the hard way over the course of the first offering, and will build in time for this in future offerings.

Overall, the experience of designing and teaching this course has been highly positive for both the instructors and the students. We have challenged many of the current structures of the university and made demands on ourselves that exceed
the efforts normally associated with developing and teaching an undergraduate course.

CONCLUSION AND DISCUSSIONS

The first offering of our course succeeded in helping students from diverse backgrounds and skill-levels learn to think and communicate spatially. Over 96% of the students who completed the course received a passing mark (D or better), with very few low numbers of failures; 88% passed with C+ or better, and 62% B or better. We believe that the unique focus of our course for early undergraduate university students goes a long way towards advancing our understanding of what is possible to achieve in teaching complex concepts and skills in large enrollment courses.

Although our class size was large and the course subject was novel for undergraduate curricula, we created effective learning environments in our laboratory sessions where students could directly interact with an instructor, a TA, and their fellow classmates. By providing hands-on experience, students had the opportunity to practice and communicate with each other. The existence of a major course project required initial laboratory sessions to be focused on providing students with the skills necessary to complete their AMTs.

One of the main sources of satisfaction for students, TAs, and instructors alike, was seeing the final projects work—there were more than 50 projects completed successfully. Because students were creating an AMT of their own design, they felt a sense of ownership over the project so that concepts taught throughout the course were no longer the main focus, but were tools needed to arrive at a functioning AMT.

While the course team is reasonably satisfied that we achieved the main course objectives, our next offering of the course is currently undergoing further reflection and refinement as we seek to incorporate the many lessons learned from the course described in this paper. One of our major successes lies in the fact that all the course instructors are eager to return to the classroom to effect the improvements.

ACKNOWLEDGMENTS

We are particularly indebted to our TAs, Bernadette Currie, Tim Chueh, Yin He, Jimmy Koo, Maryam Mokhtarmaleki and Roham Sheikholeslami, all of whom gave unstintingly of their time and expertise, much beyond their paid hours. Without their efforts, we could simply not have presented the course as described. In addition, Ms. Currie’s expertise in SolidWorks was invaluable, and appreciated. We also thank the students of TECH 106: Spatial Thinking and Communicating, for the many lessons they taught us about teaching and designing this course. Last but not least, we would like to acknowledge that all the authors of this paper, irrespective of where their names appear, have contributed significantly to its planning, writing, and revision.

REFERENCES

**APPENDIX A: COURSE MAP**

**TABLE I
COURSE ASSESSMENT MAP FOR SPATIAL THINKING AND COMMUNICATING**

**TECH 106: Spatial Thinking and Communicating – Course Assessment Map**

<table>
<thead>
<tr>
<th>Audience Characteristics:</th>
<th>Course Intent:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• First-year university students from diverse backgrounds with a range of abilities and interests.</td>
<td>• Expose students to spatial thinking concepts, graphical representation and communication.</td>
</tr>
<tr>
<td></td>
<td>• Provide a foundation of basic knowledge and technical skills for students to envision 3D structures, visualize and think in 3D, analyze spatial thinking problems using sketching, digital and physical modeling.</td>
</tr>
<tr>
<td></td>
<td>• Enhance the students’ spatial thinking abilities and skills (see and understand the world in new and useful ways).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Course Learning Objectives</th>
<th>Assessment Strategy</th>
<th>Student Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>By the end of this course, it is hoped that students will be able to:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Describe and use spatial thinking.</td>
<td>Assignments:</td>
<td>Activity-based individual Labs and Homework:</td>
</tr>
<tr>
<td>2. Use graphical representations and communication in different problem domains such as engineering, arts and business.</td>
<td>• Labs and homework: 30%</td>
<td>• Concept map.</td>
</tr>
<tr>
<td>3. Examine and interpret 3D representations.</td>
<td>• Mid-term exam: 20%</td>
<td>• Digital gimbal model.</td>
</tr>
<tr>
<td>4. Visualize and define spatial problems and proposed solutions.</td>
<td>• Final exam: 25%</td>
<td>• Physical gimbal model.</td>
</tr>
<tr>
<td>5. Create and manipulate 2D and 3D representations of their solutions to given spatial problems.</td>
<td>• Project (team-based): 25%</td>
<td>• Reports.</td>
</tr>
<tr>
<td>7. Use a computational modeling tool (such as a computer-aided design system).</td>
<td>• Test for knowledge of concepts.</td>
<td>• Pencil and paper sketches using grid paper.</td>
</tr>
<tr>
<td></td>
<td>• Scaffolding skills and concept development.</td>
<td>• Sketches showing isometric views and perspectives.</td>
</tr>
<tr>
<td></td>
<td>• Practice-based feedback from instructor/TA.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Independent and team-based.</td>
<td>Activity-based Group Project:</td>
</tr>
<tr>
<td></td>
<td>• Peer-to-peer feedback.</td>
<td>• Phase I – Representing ideas in sketches and annotation.</td>
</tr>
<tr>
<td></td>
<td>• Peer-assessment.</td>
<td>• Phase II – Parts and Whole – Digital AMT in SolidWorks.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Phase III – AMTs Realized – Digital and physical models.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Presentation &amp; competition.</td>
</tr>
</tbody>
</table>

**Resources:**

- Sketching with pencil and paper, digital Lego software, physical Lego parts, CAD software (SolidWorks), physical materials.
- Presentation technologies (ppt, etc.).
- Learning Management System (WebCT used in delivery of course).
# APPENDIX B: COURSE PROJECT ASSESSMENT MAP

## TABLE II

### GROUP PROJECT ASSESSMENT MAP FOR SPATIAL THINKING AND COMMUNICATING

**TECH 106: Spatial Thinking and Communicating – Group Project Assessment Map**

**Project Intention:**
- Assist students to develop the ability and skills to think and communicate spatially.

<table>
<thead>
<tr>
<th>Group Project (25% of course grade)</th>
<th>Objectives</th>
<th>Student Deliverables</th>
<th>Grading Rubric</th>
</tr>
</thead>
</table>
| Phase I – Representing ideas in sketches and annotation (30%) | - Analyze existing AMTs provided in lab.  
- Determine how the mechanical box relates to the figure.  
- Propose a new AMT with its animated figure and mechanical box.  
- Present your idea to class (describe figure, how to achieve the necessary movement using mechanical box). | - Figure concept.  
- Mechanical box.  
- Presentation of concept to others. | 1. Feedback from instructor and TA on proposal and sketches.  
2. Major design changes will not be possible once proposal approved. |

| Phase II – Parts and Whole – Digital AMT model in SolidWorks (25%) | - Individual – become familiar with Solid works (two tutorials in lab).  
- Group – construct the component parts developed in Phase I using SolidWorks.  
- Group – assemble individually modeled components into mechanisms in the mechanical box model using SolidWorks.  
- Group – transform figure sketches into SolidWorks model (use abstractions).  
- Group: combine mechanical box and figure into a complete SolidWorks model that simulates AMT with moving parts as described in concept sketches. | - Individual digital components  
- Group: digital model of AMT with moving parts. | Digital Model:  
1. Parts: Reasonable match with corresponding sketches.  
2. Preliminary Assembly: Parts put together, captures design intent of AMT: functionality, structure, size, location, and spatial properties. |

| Phase III – AMTs Realized – Digital and physical models (30%) | - Modify digital models based on feedback received.  
- Produce components of AMTs.  
- Construct a box and attach assembled mechanisms.  
- Construct figure and mechanisms.  
- Attach figure to box. | - SolidWorks model of modified AMT.  
- Physical model of AMT.  
- One-page report describing how materials were chosen and modeling process, justification of materials selected, alternative materials and how “joints” were implemented. | Physical Model:  
1. Functionality:  
   - Design  
   - Ease of use  
   - Reliability  
2. Aesthetics:  
   - Construction.  
   - Artistic impression. |

| Presentation & competition (15%) | - Short written report outlines what you learned about spatial thinking in the context of the course project.  
- Reflect upon the process the group went through from sketching to digital and physical design to construction of physical toy. Also the report should:  
   - Relate to spatial thinking concepts learned in class.  
   - Describe AMT design, mention reasoning involved in designing the AMT (e.g. explain types of motions, etc.).  
   - Describe issues encountered during the design.  
   - Summarize design process and include recommendations for future project ideas. | - Short Written report (750-1000 words).  
- Group presentation.  
- Peer evaluated.  
- Instructor evaluated. | Presentation:  
1. Organization  
   - clear results, sufficient detail.  
2. Visual Aids:  
   - graphic images, photos, drawings, physical prototypes.  
3. Project demonstration:  
   - mechanism works, reliable, reasonable complexity, appealing AMT  
4. Familiarity with project (Q&A).  
5. Time limit (20 min). |

### Resources for Group Project:
- Pencil and paper, digital lego, physical lego, SolidWorks, physical materials and supplies.
- Presentation technologies (ppt, etc.).