

---

## **AC 2012-4305: THE ROLE OF OBSERVATIONAL SKETCHING IN FORMING AND MANIPULATING GRAPHICAL LIBRARIES**

**Dr. Diarmaid Lane, University of Limerick**

**Dr. AJ Hamlin, Michigan Technological University**

AJ Hamlin is a Senior Lecturer in the Department of Engineering Fundamentals at Michigan Technological University, where she teaches first year engineering courses, including an Introduction to Spatial Visualization course. Her research interests include spatial visualization and educational methods. She is an active member in the Engineering Design Graphics Division of ASEE and is currently serving as the Associate Editor of the Engineering Design Graphics Journal.

**Ms. Norma L. Veurink, Michigan Technological University**

**Dr. Niall Seery, University of Limerick**

## The Role of Observational Sketching in Forming and Manipulating Graphical Libraries

The ability to externalize libraries of visual mental imagery through freehand sketching is a complex cognitive skill. Lane <sup>[1]</sup> devised and empirically validated a model of developmental exercises which ranged along a continuum from observation to imagination. The purpose of the model was to promote freehand sketching as a sense making tool while developing the ability to form, manipulate, synthesize and communicate graphical libraries. The study described in this paper, investigated the effectiveness of one exercise from the continuum which was called '*Enquiry*'. The focus of this exercise was on developing the ability to observationally sketch perspective representations of physical, regular geometries using a specially designed '*picture plane*' device.

A total of 264 students across two international universities participated in the study which consisted of two phases. '*Phase One*' was carried out at the University of Limerick with 150 students through a graphics module for undergraduates of initial technology teacher education. The students completed '*Enquiry*' as part of a three week set of exercises which aimed to develop fundamental freehand sketching skills. Upon completion of '*Enquiry*', a survey was used to determine levels of student motivation and performance. All sketches were recorded and independently analyzed.

'*Phase Two*' was carried out at Michigan Technological University with a total of 114 students, all of whom were undergraduate engineers. The purpose of this phase was to build on the findings of '*Phase One*' within an alternative discipline that depends on developing graphical competencies. The exercise was completed during one class of a fourteen week, first year "*Introduction to Spatial Visualization*" course. The purpose of '*Enquiry*' in this instance was to develop students' ability to manipulate, explore and communicate different views of geometries prior to formally learning about orthographic projection. Student surveys and classroom observations were recorded by the teachers.

High levels of student motivation were observed during both phases and the students evidenced a clear understanding of the picture plane and its relationship with perspective drawings. The paper also reports that a number of ergonomic improvements which were made to the sketching equipment (subsequent to '*Phase One*') were beneficial and that these enabled more controlled and reflective exploration of complex geometries. The manner in which students completed the activity during both phases of the study varied. Some students performed the exercise in a slow, controlled and reflective manner, resulting in sketches which were precise, with significant levels of exploration evidenced. In contrast, other students completed the exercise in an automatic and reflexive fashion, resulting in less detail being explored but a greater number of views were communicated.

The presented study highlights the important role of observational sketching in developing students' understanding of various ways to graphically represent objects. Furthermore, it highlights the critical, intermediate role of observational sketching in forming graphical libraries of visual mental imagery which can be retrieved and manipulated during more advanced conceptual, design based activities.

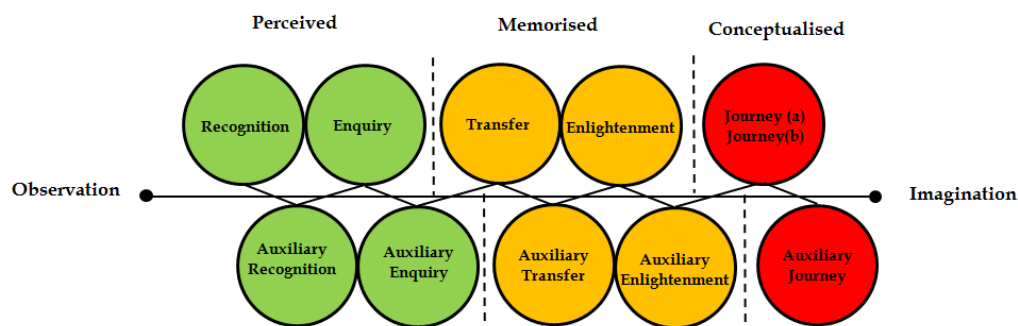
## **Background**

The ability to externalize visual ideas has significance in engineering education where creative design is regarded as the coordinated co-generation of concepts and perceptual findings through external representations such as sketches <sup>[2]</sup>. The externalization of visual ideas and visual imagery facilitates its reorganization, reconceptualisation and reformulation <sup>[3]</sup>. The construction of a set of concepts into external representations has a modeling effect which leads to new discoveries and hypotheses <sup>[3]</sup>.

Sketching has experienced little change since Leonardo da Vinci (1452-1519). The uniqueness of hurried and untidy sketches incorporating rough hatching and linetypes using mediums such as crayon, pencil or watercolor on scrap pieces of paper remains unchanged. Examination of the unique attributes of sketches gives an insight into the underlying cognitive processes that occur during the production of external representations <sup>[4]</sup>. The attributes of sketches include the following:

- Sketches use two dimensional sign systems that include descriptive linetypes as well as written notes to represent three dimensional visual information <sup>[4, 5]</sup>.
- Linetypes and sign systems that are communicated in sketches are descriptive and depictive in nature and assist in the mental gymnastics between two modes of visual representation.
- Sketches contain both selective and disjointed information. They are records of a sequence of acts that combine visual perceptual information with images generated from memory <sup>[4]</sup>.
- Sketches contain deliberate or accidental indeterminacies to help rouse the mind to creative thought processes and invention. Indeterminacies include scribbles, smudges, rough cross hatching, dark mysterious areas of shadow and shade as well as empty or negative space.

The demand for sketching is stimulated by the need to foresee the results of manipulation and synthesis of objects without actually seeing or executing such operations <sup>[4]</sup>. The utilization of scaffolds such as words, pictures and models as imitations of objects, scenes or events not physically present, significantly increases the ability to engage in mental visualization <sup>[4]</sup>. In order to address deficiencies in the research literature associated with freehand sketching, Lane <sup>[1]</sup> devised and empirically validated a model of activities (Figure 1) which facilitated the development of sketching expertise.



**Figure 1 – Model of drawing and sketching activities**

The model progresses from left to right where the perception based ‘*drawing*’ activities on the left are controlled and reflective in nature with a high degree of visual scaffolding. In contrast, the conceptual ‘*sketching*’ activities on the right are automatic and reflexive in nature and the visual scaffolds are removed. The strength of the model lies in its potential to promote students’ progression across the three stages of development through perceived, memorized and conceptualized activities. The perception based activities build students’ “*graphical libraries*”<sup>[6]</sup> as they are constantly able to refresh vivid perceptual snapshots while composing their drawings<sup>[4]</sup>. The memory focused activities in the centre of the model develop student’s ability to access their “*graphical libraries*” through “*visual mental imagery*”<sup>[7]</sup> and to communicate these through sketching. The final conceptually focused phase of the model promotes students ability to manipulate and synthesize their “*graphical libraries*” through tasks which are imaginative and reflexive in nature.

In order to facilitate the progression away from observational drawing as a 2D ‘*copying*’ activity towards conceptual type sketching it is necessary to consider the cognitive skills which should be developed. The communication of ‘*graphical libraries*’ is dependent on the ability to form, retrieve, manipulate and communicate visual mental imagery. The initial formation of these graphical libraries is promoted by the physical manipulation and communication of 3D physical objects. The focus of this paper centers around the ‘*Enquiry*’ activity, which is a perception focused activity which is designed to aid students in physically manipulating and communicating physical objects. The rationale for ‘*Enquiry*’ together with its implementation in two international universities is described in the next section.

## Research Method

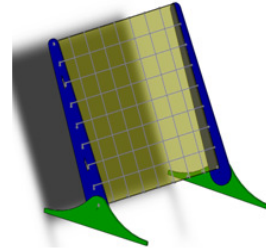
‘*Enquiry*’ is an observational drawing based activity which was designed to aid students’ in progressing from drawing as a 2D ‘*copying*’ activity to a more complex and challenging 3D to 2D ‘*conversion*’ activity. The development of the activity took place over two phases. ‘*Phase 1*’ was conducted at the University of Limerick with a cohort of 150 undergraduate students of technology teacher education through a design and communication graphics module of study. ‘*Phase 2*’ was informed by the findings of ‘*Phase 1*’ and it was conducted at Michigan Tech with a cohort of 114 undergraduate engineering students through an ‘*Introduction to Spatial Visualization*’ course of study. The rationale, application and findings for ‘*Phase 1*’ are described next.

### Phase 1

**Rationale:** The purpose of ‘*Enquiry*’ during ‘*Phase 1*’ was to establish how students could effectively and accurately communicate physical 3D geometries on a flat surface. Inspired by the ‘*Perspective Machine*’ of Renaissance artist, Albrecht Dürer, a novel 3D to 2D conversion device was designed (Figure 2). This enabled the image of a 3D physical object to be traced on to a flat surface or ‘*picture plane*’.



Perspective Machine by Albrecht Dürer



3D to 2D Conversion Device

Figure 2 – Perspective Machines

The ‘*Enquiry*’ activity was considered beneficial to student’s development for several reasons:

- The activity allows students to construct their own understanding of perspective projection and the role of the picture plane.
- The activity promotes creativity and it allows students to manipulate 3D physical objects in a range of different orientations.
- The activity significantly enhances students’ ability to analyze and enquire into intricate geometries that exist within compositions.
- The activity benefits students in developing their spatial visualization skills and their ability to mentally manipulate and communicate regular geometries.
- The 3D to 2D conversion device was designed so that it was ‘*hands-free*’ (Figure 2). This makes the task of drawing on the plane simple and easy to do.

For ‘*Phase 1*’, it was decided that a range of regular geometries, configured in a number of complex combinations would be utilized (Figure 3). There were specific reasons for selecting regular geometries such as spheres, cones, cubes and rectangular prisms. All of the students had studied graphics during their previous two years of study and they were comfortable with solving 2D problems involving these regular geometries. It was anticipated that the physical manipulation and communication of these physical models would stimulate and develop students’ individual ‘*graphical libraries*’<sup>[6]</sup>. The synthesis and communication of these ‘*graphical libraries*’ is necessary during more advanced conceptual based sketching activities.

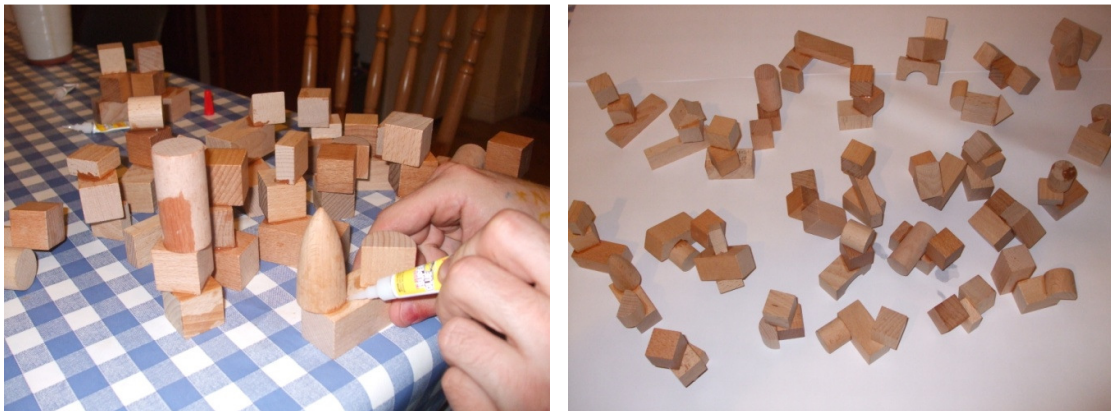
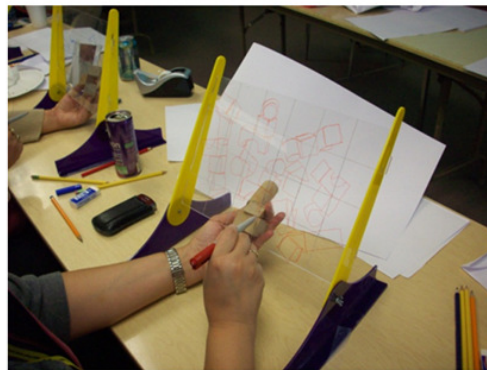


Figure 3 – Regular geometries configured in a range

## Application

1. The students were provided with a variety of configurations from which they could select.
2. Using a felt tipped pen, the students proceeded to trace the geometries of each configuration onto the picture plane (Figure 3). They were encouraged to manipulate the objects into different orientations and to capture the geometries as accurately as possible.
3. Once the composition was recorded on the 2D picture plane, the students' transferred the geometries on to their sketch pads with the aid of a grid.
4. The students' were encouraged to constantly evaluate their sketch and relate it to the physical composition.
5. The students were allowed thirty minutes to complete the activity.
6. Upon completion the students were provided with a survey where they were afforded the opportunity to comment on the activity.



Tracing on to the Picture Plane

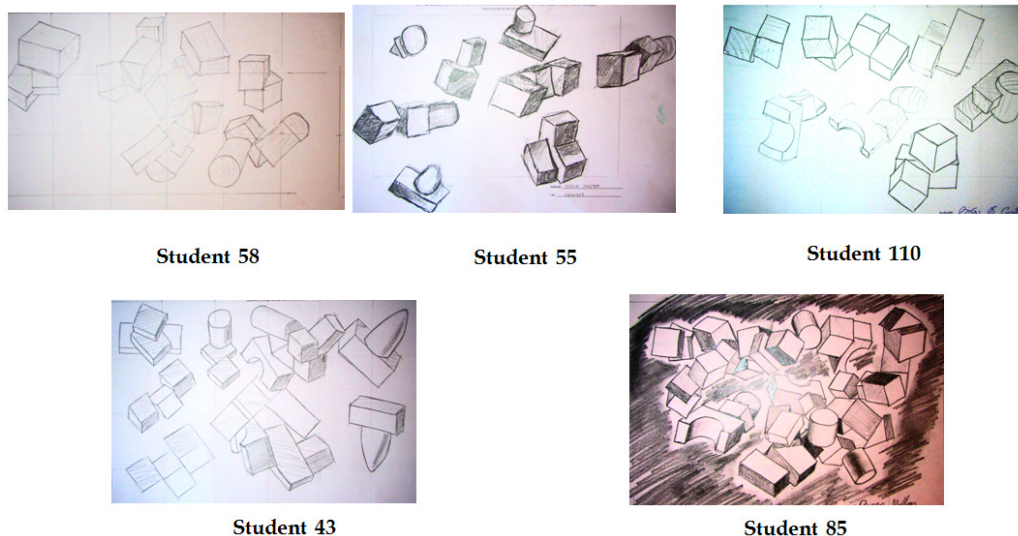


Copying the drawing to the sketchpad

Figure 4 – Classroom application of 'Enquiry' activity

## Findings

A selection of students' sketches is shown in Figure 5. It is evident from the sketches that some students' communicated more detail than others. For example, both Student 58 and Student 55 communicated the same amount of configurations; however Student 55 evidenced more detail through deliberate hatchings and renderings.



**Figure 5** – Selection of student sketches for Enquiry Activity

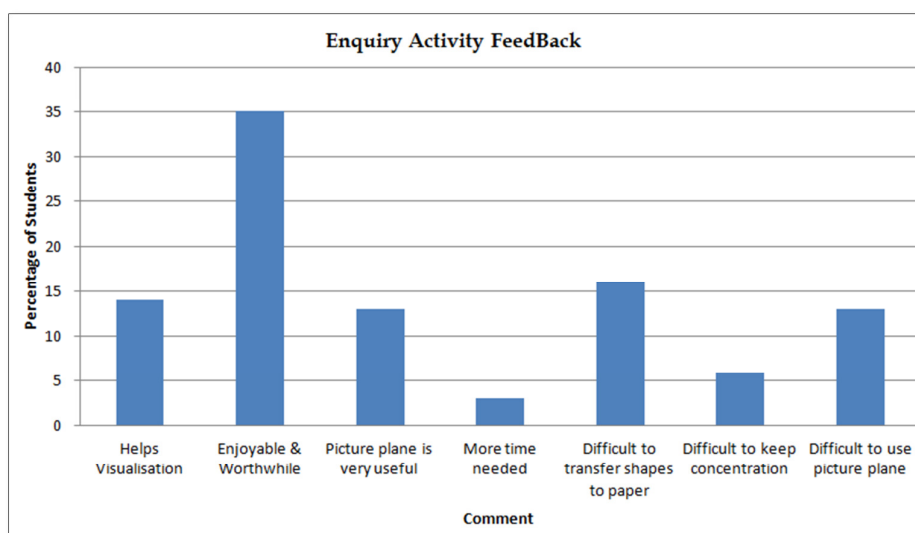
Interestingly, the feedback comments provided by these students suggest why Student 55 might have engaged better in the activity (Table 1). The feedback from Student 58 suggested that the 3D to 2D conversion device was difficult to use and that it required some ergonomic improvements.

**Table 1** – Selected student’s feedback for Enquiry

Student comment	Feedback Comment Provided for Enquiry
Student 58	<i>“The enquiry activity was more difficult as the shapes were somewhat difficult to hold and draw but the idea behind it is very good”</i>
Student 55	<i>“Excellent exercise. Helps to build confidence ”</i>

All of the comments for the entire cohort were analysed and coded. These data are presented in Figure 6.





**Figure 6 – Enquiry Feedback for Phase 1**

The feedback comments were largely positive and the students generally found the activity beneficial and enjoyable. A selection of these positive comments is shown in Table 2. However, it was notable that 29% of students claimed that it was either difficult to use the picture plane or difficult to transfer the geometry to paper. A selection of these comments is shown in Table 3.

**Table 2 – A selection of comments indicating the benefit of the ‘Enquiry’ activity**

Student comment	Feedback Comment Provided for Enquiry
Student 24	<i>Very useful when it comes to sketching these very difficult shapes and designs</i>
Student 112	<i>I thought it was a very enjoyable lab with good exercises which could be used with a junior or senior grade drawing class</i>
Student 134	<i>I found this good as it is practical sketching, visualizing and also adding color and shading</i>
Student 103	<i>Helped sketching what you see and not what you think you see. Improved drawing curves and shapes. I feel I improved at sketching</i>
Student 25	<i>Very good for learning to draw what I would have thought to be complex components</i>
Student 31	<i>This is a great task. The transfer between 3D to 2D is difficult to begin with but as you continue through different objects it becomes easier</i>

**Table 3 – A selection of comments indicating difficulties with the ‘Enquiry’ activity**

Student comment	Feedback Comment Provided for Enquiry
Student 117	<i>“Got very confusing on the picture plane. Difficult to hold everything in place while copying object”</i>
Student 28	<i>“Drawing the objects right on the picture plane was hard”</i>
Student 44	<i>“It is very hard to draw shapes on the perspex but very helpful in order to improve your sketching ability”</i>
Student 60	<i>“Balancing the objects on the picture plane was tricky and kind of led to mistakes in the sketch”</i>



In order to further develop and improve the ‘*Enquiry*’ activity, it was considered important to highlight the main issues of concern from ‘*Phase One*’ prior to its implementation at Michigan Tech during ‘*Phase Two*’. These issues and recommendations are presented in the next section.

## Recommendations for Phase 2

The findings from ‘*Phase 1*’ highlight that ‘*Enquiry*’ was a very worthwhile activity which stimulated enjoyment and interest while at the same time it was regarded as a cognitively challenging and beneficial activity by the students. In terms of improving the activity prior to implementation in ‘*Phase 2*’ a number of recommendations were made. These include the following:

- Issue:** A number of students claimed that it was difficult to draw on the 3D to 2D conversion device as it became unsteady as they sketched on the plastic plane.  
**Recommendation:** As the device was very light and constructed entirely from acrylic, it was suggested it should be either be constructed from a heavier material or be fitted with a stabilizer such as suction cups.
- Issue:** The 3D to 2D device was designed so that it could be assembled and disassembled into a flat pack. However, there was an issue with breakages in the joining clips on the clear acrylic picture plane (Figure 7).  
**Recommendation:** It was advised that the clips should be eliminated from the design of the picture plane and that the side supports should be designed with a suitable groove to facilitate ease of removal and flat storage of the picture plane device.

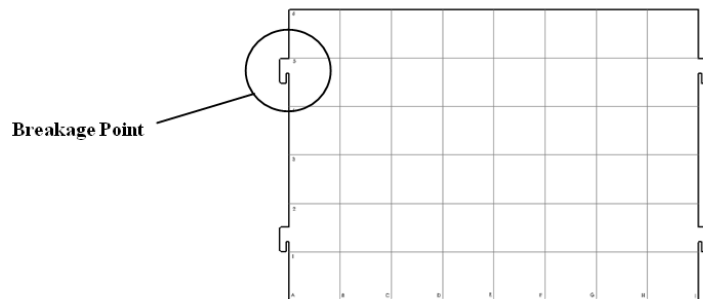
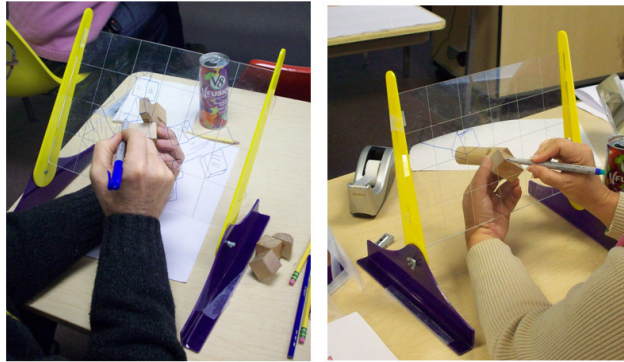


Figure 7 – Flaw in the clear acrylic picture plane

- Issue:** Some students claimed that it was difficult to hold objects behind the clear picture plane while sketching the image (Figure 8).  
**Recommendation:** It was recommended that some form of a device should be utilized to hold the object behind the plane and allow the students to have both hands free. This device should be flexible enough to hold the physical objects in a range of orientations and distances from the plane.



**Figure 8 – Difficulty with holding the object behind the picture plane**

The next section of the paper describes the rationale for implementing ‘*Enquiry*’ at Michigan Tech during ‘*Phase Two*’, a description of how the activity was applied (including how the recommendations were addressed), the subsequent findings and recommendations.

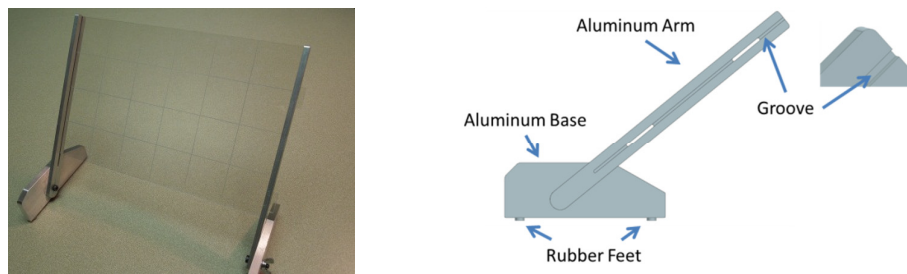
## **Phase 2**

### **Rationale**

The purpose of incorporating the ‘*Enquiry*’ activity into the Introduction to Spatial Visualization course at Michigan Tech was to help develop students’ spatial skills and their ability to mentally manipulate 3D objects and represent them in a 2D plane. The instructors for this course felt the activity would encourage students to imagine the rotations (of the object or of the students themselves about the object) required to generate orthographic drawings. Therefore the ‘*Enquiry*’ activity was inserted into the course schedule after Isometric Drawing and before Orthographic Drawing. A second activity using the 3D to 2D conversion device, the ‘*T activity*’, was added to the orthographic drawing lesson to illustrate the similarities and differences between isometric sketches, perspective sketches, and orthographic sketches.

### **Application:**

Several improvements were made to the 3D to 2D conversion devices (Figure 9), based on recommendations from Phase 1.



**Figure 9 - Improved 3D to 2D Conversion Device**

1. To reduce movement of the device when sketching on the picture plane, the side supports were made more substantial and constructed from aluminum rather than acrylic. Additionally, two rubber feet were added to the bottom of each side support shown in Figure 9.
2. To reduce flexion and breakage of the plexiglass picture plane, a groove was cut in the side supports.
3. To make the '*Enquiry*' activity completely hands-free, a block holding device, shown in Figure 10, was created to allow the geometric objects to be held in a variety of orientations behind the picture plane. The device was made from a bendable bubble book light in which the light was removed, leaving a bendable coil and a flat surface. Velcro hook pieces were attached to the flat surface. Pieces of Velcro loops were attached to the objects that were sketched.

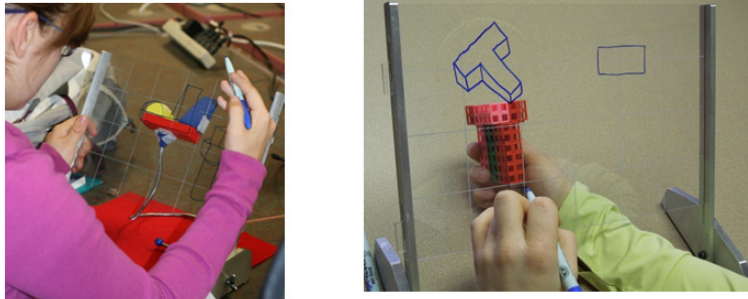


**Figure 10 - Block Holding Device**

Two activities were conducted with the 3D to 2D conversion devices. The first activity was the '*Enquiry*' activity described in Phase 1. In the second activity, the '*T*', was used to introduce orthographic projections.

For the "*Enquiry*" activity:

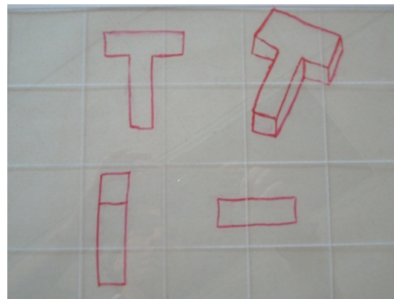
1. Each student assembled their 3D to 2D conversion device.
2. Groups of one to three students were provided with 4-6 objects to share for this exercise. The objects were similar in nature to those used in Phase 1 with two modifications: 1) several pieces of Velcro were attached to each object to fasten it to the holding device, and 2) some of the blocks were multi-colored.
3. Students were instructed to trace the geometries of several objects in several different orientations onto the picture plane using a wet-erase felt-tip pen.
4. Students transferred the geometries onto paper lined with a grid.
5. Students were given approximately 45 minutes for this activity.



**Figure 11 – Classroom application of Phase 2 Activities**

For the “T” activity:

1. Students created a ‘T’ from snap cubes.
2. Students were instructed to sketch their ‘T’ from 1) any angle, 2) the top, 3) the front, and 4) the side on the picture plane. Students did not transfer these sketches to paper.
3. Students were given 5-10 minutes to complete their sketches. A sample student sketch is shown in Figure 12.
4. Student sketches were compared to isometric and perspective sketches, and orthographic projections of the “T”.



**Figure 12 - Sample student sketch from "T" activity**

This second activity was followed by a short lecture on creating orthographic projections. Students worked through a software module on orthographic drawings that included demonstrations and exercises and then completed exercises in their workbook <sup>[8]</sup>. At the end of class students were given the survey shown in Figure 13. This survey was the same as that given to students Fall 2007, with the addition of item 6d (*‘Manipulatives’* – Picture Plane).

### EVALUATION OF MODULE BY STUDENTS

Please take a few minutes to fill out this evaluation form. Your responses will help us arrange future materials to fit the needs of students. Feel free to use the back of this form for any additional comments.

1. Overall, how would you rate the quality of this module?  

1	2	3	4	5
Poor	Fair	Good	Very Good	Excellent
2. The length of the module with respect to the activities was:  

___too short	___appropriate	___too long
--------------	----------------	-------------
3. For my learning purposes, the overall level of this module was:  

___too simple for my needs	___appropriate to my needs	___too advanced for my needs
----------------------------	----------------------------	------------------------------
4. Approximately how much time did you spend on this module outside of class? \_\_\_\_\_
5. Overall, I enjoyed this module.  

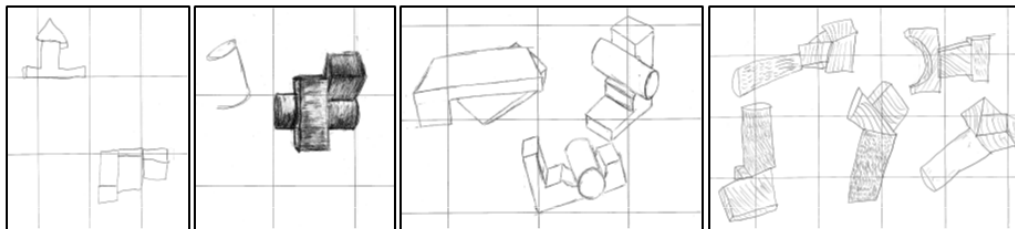
1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
6. Each of the following was beneficial to my understanding of the material.

	Not Applicable	Strongly Disagree	Disagree	Agree	Strongly Agree
a. Instruction (lecture and demonstration)	N/A	1	2	3	4
b. 3-D Spatial software	N/A	1	2	3	4
c. Workbook Problem Sets	N/A	1	2	3	4
d. Manipulatives – Picture Planes	N/A	1	2	3	4
e. Manipulatives - Blocks	N/A	1	2	3	4
f. Interaction with the instructor(s)/TA(s)	N/A	1	2	3	4
g. Interaction with other students	N/A	1	2	3	4
7. Suggest improvements for this module
8. During this module I worked:    alone    in a group of 2    in a group of 3    in a group of 4 or more
9. Briefly describe the methods or strategies that were most helpful to you as you completed this module.

**Figure 13 - Survey given to students at the end of the orthographic drawing module that included the "T" activity**

### Findings:

Several student sketches from the 'Enquiry' activity are shown in Figure 14. As shown, students communicated a wide range of detail in their sketches with most sketches resembling the two sketches on the right.



**Figure 14 - Selection of student sketches from Phase 2 "Enquiry" activity**

Students verbally reported that they enjoyed the 'Enquiry' activity. Survey responses to Question 5, also indicated that overall students enjoyed the orthographic drawing lesson, which included the 'T' activity.

A comparison of averaged student responses to survey Questions 1-5 for the orthographic drawing module from Fall 2007 and Fall 2011 is shown in Table 4. The Fall 2011 module was the same as the Fall 2007 module with the addition of the 'Enquiry' and 'T' activities. One important difference between these groups of students is that the students in 2007 elected to take the class, while the students in 2011 were required to take the class based on their score on the Purdue Spatial Visualization Test: Rotations. The Fall 2007 students represent responses from one section of the class, while the Fall 2011 responses are from four sections of the class. While the differences between the responses for all questions shown in Table 4 are not statistically significant, it is interesting that the averaged responses from Fall 2011 students suggest that their level of enjoyment was higher than the Fall 2007 students, despite the fact that the Fall 2011 students were required to the class.

**Table 4 - Averaged Student Responses to Orthographic Drawing Module Evaluation**

Question	Fall 2007 Orthographic Module	Fall 2011 "T" Activity and Orthographic Module
1. Overall Quality	3.73 (n=11)	3.45 (n=71)
2. Length of Module	2.18 (n=11)	2.13 (n=71)
3. Level of Module	1.91 (n=11)	1.83 (n=71)
4. Time Spent on Homework	40 minutes (n=11)	53 minutes (n=64)
5. Overall Level of Enjoyment	3.18 (n=11)	3.42 (n=71)

The overall quality of the module was rated between good and very good both years with the Fall 2011 students feeling slightly less satisfied than the Fall 2007 students. One potential explanation could be general dissatisfaction with the course software as evidenced by student comments from Question 7 – Suggested Improvements, shown in Table 5.

**Table 5 – A selection of student comments indicating general dissatisfaction with module software**

Student	Comment
Student 11	<i>I feel that the software makes me feel stupider, I like working with my hands, blocks, pencil/paper rather than staring at the screen.</i>
Student 35	<i>The software was 100% repetitive of what we already learned from the lecture, I don't feel that it was necessary.</i>
Student 39	<i>Better software.</i>
Student 40	<i>Less time on the computer, more with practice/in class exercises, help with homework.</i>

The averaged responses to Question 2 and 3 were near 2 both years, indicating that the students felt the module was about the appropriate length and the appropriate level. Values less than 2 indicate the module was too short or too simple and values greater than 2 indicate the module was too long or too advanced.

As shown in Table 4, the Fall 2011 students reported spending slightly more time out of class to complete their assignment than the Fall 2007 students. This is expected since the 'Enquiry' and 'T' activity were added to the module for Fall 2011 giving students less time (approximately 15 minutes) to complete their homework during class.

Overall student responses indicate that the '3D to 2D conversion devices' were not as beneficial to the students' understanding of orthographic drawings as some of the other components such as the workbook problems, using the blocks and working with other

students. However, when students were asked to describe the methods or strategies that were most helpful, several students indicated that these devices and activities were most helpful in completing the orthographic drawing module as shown in Table 6.

**Table 6 - A selection of student comments describing the methods or strategies that were most helpful as they completed the module on orthographic projections**

Student	Comment
Student 61	<i>Picture plane work from two weeks before ['Enquiry' activity] and building blocks helped me the most</i>
Student 57	<i>The lecture and demonstrations helped me learn more about the module and the blocks and picture planes also helped me understand it better.</i>
Student 51	<i>I think drawing on the plexiglass [3D to 2D conversion device] was the most helpful</i>
Student 32	<i>Closing one eye while tracing made it easier</i>
Student 25	<i>When using blocks and screens to draw what you see</i>
Student 24	<i>I think the hands on activities help a lot</i>
Student 38	<i>Using the picture planes really helped and the lecture and practice problems (examples) helped also.</i>

### Recommendations:

The 'Enquiry' activity was successfully implemented at Michigan Tech in 'Phase 2'. The following are recommendations to improve the delivery of the activity within the 'Introduction to Spatial Visualization' course.

1. **Issue:** Several students rushed through the 'Enquiry' activity.  
**Recommendation:** Encourage students to take their time and to recommend they add additional detail to their sketches.
2. **Issue:** Flow of course topics could be improved.  
**Recommendation:** Use the 'Enquiry' activity earlier in the course so that it is the first activity in which students attempt to represent 3D objects on a 2D plane. Have students use the 3D to 2D conversion device to create perspective, isometric, and orthographic drawings. Follow the 'Enquiry' activity lesson with isometric drawing and then orthographic drawing.
3. **Issue:** Several students were challenged by the freehand sketching used in the 'Enquiry' and 'T' activities. Most of the sketching exercises the students completed for class used dot paper to help guide their sketches.  
**Recommendation:** To improve student confidence with freehand sketching provide additional freehand sketching activities such as those developed by Lane <sup>[1]</sup>.

### Discussion / Conclusion

The research study described in this paper has provided ample evidence that the 'Enquiry' activity is very effective in aiding students' to develop the ability to communicate images of 3D physical objects on a 2D flat plane. However, it should be considered that the strengths and value of the 'Enquiry' activity extend beyond the externalizations created by the students. The activity promotes enquiry into and manipulation of physical geometries and this stimulates the development of graphical libraries of visual mental images which can be



retrieved, manipulated and communicated in conceptual activities or activities involving complex mental manipulations.

The strength and versatility of the activity is highlighted in its implementation across two international universities and within different disciplines of graphics education. 'Enquiry' was applied at the University of Limerick as part of a model of developmental activities which aimed to develop expertise in freehand sketching as conceptual support tool. In contrast, 'Enquiry' was implemented at Michigan Tech as a means of developing spatial visualization skills and to help students understand conventional methods of representing objects.

The collaboration across two international universities proved very beneficial in terms of modifying and improving the apparatus used in the activity but it also provided a means of critiquing and refining the courses in which they were implemented. The recommendations from 'Phase 2' indicate that careful consideration should be given to the timing and application of 'Enquiry' within modules of study. This planning should take learning outcomes and students' prerequisite knowledge into account. For example, it may be beneficial to facilitate experiential learning of various ways to represent objects using the '3D to 2D conversion device' prior to formally teaching students about the conventions associated with orthographic, isometric and perspective projection.

Finally, it should be considered that although the findings from this study are very positive they are subjective in nature. Future research should empirically analyze the effectiveness of the 'Enquiry' activity and associated activities <sup>[1]</sup> in terms of their potential in promoting the development of spatial visualization skills and visual thinking across different disciplines of graphics education.

## Bibliography

1. Lane, D., *Developing Sketching Expertise within Technology Education*, Ph.D. 2011, University of Limerick: Limerick.
2. Suwa, M., Tversky, B., *External Representations Contribute to the Dynamic Construction of Ideas in Diagrammatic Representation and Inference*, M. Hegarty, Meyer, B., Narayanan, N.H., Editor. 2002, Springer Berlin / Heidelberg. p. 341-343.
3. Suwa, M., Tversky, B. *How do designers shift their focus of attention in their own sketches?* in *Papers from the AAAI-97 Fall Symposium*. 1997: AAAI Press.
4. Fish, J., Scrivener, S., *Amplifying the Mind's Eye: Sketching and Visual Cognition*. Leonardo, 1990. **23**(1): p. 117-126.
5. Deregowski, J.B., *Illusions, Patterns and Pictures*. 1970, New York: Academic Press.
6. Storer, I., *Reflecting on professional practice : capturing an industrial designer's expertise to support the development of the sketching capabilities of novices*. Design and Technology Education: An International Journal, 2008. **10**(1): p. 19.
7. Borst, G., Kosslyn, S.M., *Visual mental imagery and visual perception: Structural equivalence revealed by scanning processes*. Memory & Cognition, 2008. **36**(4): p. 849-862.
8. Sorby, S., Wysocki, A.F., Baartmans, B.J., *Introduction to 3D Spatial Visualization: An Active Approach*. 2003, Clifton Park, New York: Thompson Delmar Learning