AC 2011-842: A PRELIMINARY INVESTIGATION OF USING WRITING AS A CRITICAL THINKING TOOL

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A PRELIMINARY INVESTIGATION OF USING WRITING AS A CRITICAL THINKING TOOL IN CONTEMPORARY MATHEMATICS

Abstract

This study examines the relationship among learning, writing, critical thinking, and knowledge retention. Having noted students' surprise at failing a math placement test when they believe they "know" the material on it, the author hypothesizes that a lack of critical thinking about the material in earlier math courses allows students' memory of it to fade over time. The author uses Bloom's Taxonomy, as modified and published in 2001, to show the need for higher-level thinking to facilitate knowledge retention. Writing is used as a principal strategy for stimulating critical thinking among students studying Contemporary Mathematics at Virginia Commonwealth University in Qatar, located in Doha, Qatar. Studies involving three such classes during the 2010-2011 academic year will incorporate critical thinking assignments via writing requirements and test the effects of these assignments on students' retention.

INTRODUCTION

Math and science faculty at the Middle Eastern branch of Virginia Commonwealth University located in Doha, Qatar (VCUQatar) in August 2008 were shocked when, of approximately 36 incoming students taking a mathematics placement test, *only two passed.* In addition, these two students passed only because the minimum passing score was adjusted downward from that required by the home campus to accommodate the diverse backgrounds and language challenges of a multinational student body. Because these were the only students who qualified that year to take the non-remedial, required math course, MATH 131, Contemporary Mathematics, it could not be offered during the Fall Semester. According to Dr. John Schmeelk, one of the placement test administrators, "Students who challenge their placement in the remedial course say they 'know' the material, just forgot, or were not ready for the test. However, the lowness of their scores does not support their claims[1].

Similarly, during the Fall Semester of 2010, students taking an interior design course on the historic influences of specific design types struggled to complete one of their written assignments and asked for substantial help from their university's writing center. Their assignment required students to "analyze an informational video clip which demonstrates an aspect of historical design related to the Middle-Ages period"[2]. The students were first to describe the video selected and their reasons for selecting it. Then they were to analyze how well or how poorly it addressed the topic, with the quality of their analysis being the primary criterion for the grade. Despite having previously completed analysis assignments in their English and Art History courses, students coming to the writing center invariably did not recognize the similarity among the assignments or transfer knowledge from these previous experiences to this assignment and required instruction on how to approach it.

These two episodes gave rise to the current study, which examines the relationship among learning, writing, critical thinking, and knowledge retention. Having noted students' surprise at failing the math placement test when they believe they "know" the material on it and their inability to recognize the similarity of situations and transfer analytical skills, the author hypothesizes that a lack of critical thinking about previously encountered material, which requires deeper and more extensive involvement with the material, in earlier courses allows students' memory of it to fade over time. Using data collected from their math courses, the author investigates more intentional pedagogical strategies for developing critical thinking in math.

BACKGROUND

Learning and Knowledge Retention. A key component of learning theory is Bloom's Taxonomy. The taxonomy is a hierarchically arranged categorization of six learning levels that a student must progress through consecutively, from lowest level to highest, to master a topic. Descriptions of each category describe the type of learning that must be accomplished before progressing to the next category, and educators use these descriptions to create educational objectives for courses. The taxonomy eventually emerged from discussions among educators at the 1948 Convention of the American Psychological Association who set out to classify behaviors believed to be important in the learning process. They eventually agreed on three major domains of learning: the cognitive, knowledge-based domain; the affective domain of attitudes; and the psychomotor, or skills-based domain. Their work on the cognitive domain was published in 1956 as a handbook titled *Bloom's Taxonomy of the Cognitive Domain,* after the leader of the group, the educator, Dr. Benjamin Bloom[3]. Although taxonomies exist for the affective and psychomotor domains, this study focuses on the cognitive domain.

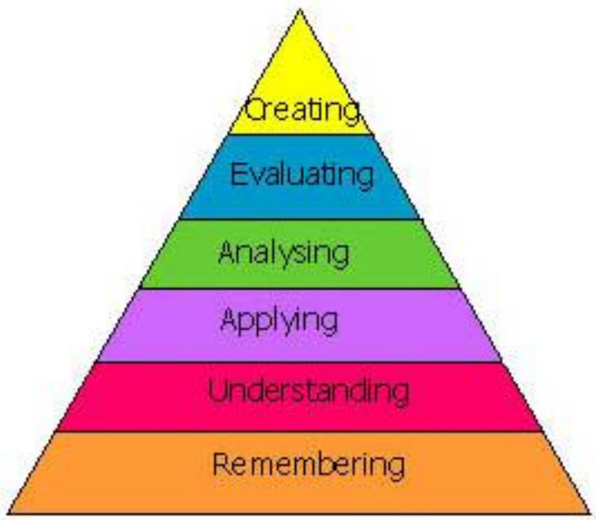

Figure 1. Bloom's Taxonomy as revised by Anderson in 2001. Source: Mary Forehand.

In 2001, a group of cognitive psychologists, curriculum theorists, instructional researchers, and specialists in testing and assessment led by Lorin Anderson, one of Bloom's former students, published an updated version of *Bloom's Taxonomy.* The revised version modified terminology, structure, and emphasis of the original taxonomy (see Figure 1) to provide " 'a clear, concise visual representation' (Krathwohl, 2002) of the alignment between standards and educational goals, objectives, products, and activities"[3].

Beginning at the bottom of the pyramid shown in Figure 1 with the lower levels of learning (remembering, understanding, and applying), the student must accomplish each in order before progressing to the next higher level. The highest levels of learning are analyzing, evaluating, and creating, and according to the widely published educational psychologist and Professor Emeritus of Valdosta State University, Dr. William G. Huitt, critical thinking emerges within these higher levels:

> In my opinion, . . . synthesis/creating and evaluation/evaluating are at the same level. Both depend on analysis as a foundational process. However, synthesis or creating requires rearranging the parts in a new, original way whereas evaluation or evaluating requires a comparison to a standard with a judgment as to good, better or best. This is similar to the distinction between creative thinking and critical thinking [see Huitt 1998]. Both are valuable while neither is superior. In fact, when either is omitted during the problem solving process, effectiveness declines[4].

Research by Garavalia, Hummel, Wiley, & Huitt in 1999 also shows that learning to handle a topic at these highest levels improves and increases students' memory of what they have learned because they must elaborate and process the information more thoroughly[4]. Thus, higher-level thinking facilitates knowledge retention.

Writing and Knowledge Retention. Writing researchers during the 1960s and 1970s studied writing as a learning method and converted into pedagogy the observation that writing helps writers capture and clarify thoughts. A key article in this work was Janet Emig's "Writing as a Mode of Learning," that claimed "writing is neurophysiologically integrative, connective, active, and available for immediate visual review,"[5] characteristics that make it an effective learning tool. The work of writing researchers James Britton and his colleagues stressed the distinct power of writing to help the writer organize and express experience. They explained that to express an experience, the writer first must capture it, investigate it, and then reflect upon his/her ideas about it. This process was found to enhance students' learning[6]. This finding reiterates Huitt's claim that the higher levels of learning (suggested by *investigation* and *reflection* in the writing researchers' work) enhance students' retention through critical thinking processes.

Critical Thinking. The definition of *critical thinking* has evolved during the last couple of decades as different fields have contributed their perspectives. Some definitions focus on the mental and physical abilities that critical thinking requires; others, on support of claims and persuasion; still others, on its systematic process and the discipline, reasonableness, criteria, responsibility, or sensitivity required. The researcher William Huitt has analyzed numerous of these definitions and proposes his own generic definition

> . . . only to more closely align the concept to the evaluation level as defined by Bloom et al. (1956) and to include some of the vocabulary of other investigators. The following is my proposed definition of critical thinking:
>
> - Critical thinking is the disciplined mental activity of evaluating arguments or propositions and making judgments that can guide the development of beliefs and taking action (Huitt 1998).

The two preceding sections have related learning and writing with critical thinking. Huitt further relates critical thinking to Bloom's Taxonomy and separates it from *creative thinking:*

> Research over the past 40 years has generally confirmed that the first four levels [of Bloom's Taxonomy] are indeed a true hierarchy. That is, knowing at the knowledge level is easier than, and subsumed under, the level of comprehension and so forth up to the level of analysis. However, research is mixed on the relationship of synthesis and evaluation [evaluating and creating, respectively, in Anderson's revised model]; it is possible that these two are reversed or they could be two separate, though equally difficult, activities (Seddon, 1978).
>
> Synthesis and evaluation [now *evaluating* and *creating*, respectively] are two types of thinking that have much in common (the first four levels of Bloom's taxonomy), but are quite different in purpose. Evaluation [now *Creating*] (which might be considered equivalent to critical thinking as used in this document) focuses on making an assessment or judgment based on an analysis of a statement or proposition. Synthesis [*Evaluating*] (which might be considered more equivalent to creative thinking) requires an individual to look at parts and relationships (analysis) and then to put these together in a new and original way.
>
> There is some evidence to suggest that this equivalent-but-different relationship between critical/evaluative and creative/synthesis thinking is appropriate. Huitt (1992) classified techniques used in problem-solving and decision-making into two groups roughly corresponding to the critical/creative dichotomy. One set of techniques tended to be more linear and serial, more structured, more rational and

> analytical, and more goal-oriented; these techniques are often taught as part of critical thinking exercises. The second set of techniques tended to be more holistic and parallel, more emotional and intuitive, more creative, more visual, and more tactual/kinesthetic; these techniques are more often taught as part of creative thinking exercises. This distinction also corresponds to what is sometimes referred to as left brain thinking (analytic, serial, logical, objective) as compared to right brain thinking (global, parallel, emotional, subjective) (Springer & Deutsch, 1993).[7]

Huitt goes on to say "Learning the process of critical thinking might be best facilitated by a combination of didactic instruction and experience in specific content areas"[7].

Research Method and Materials

Participants. Students who either had passed a math placement test or had completed the remedial course, MATH 001, and who were enrolled in the required MATH 131, Contemporary Math, course in Fall Semester 2010 were the subjects of this research. Three sections of the course contained a total of 36 students. The University is co-educational, so most classes are a combination of a few males and predominantly females ranging from freshmen to seniors. Most of the students are non-native English speakers from diverse countries, and all of them are, or plan to become, design majors.

Course Activities. Over the past several years, the teaching strategies and assignment requirements for MATH 131 have evolved to accommodate students' generally non-American cultures, their English-as-second-language (ESL) needs, and their individual learning and information-processing preferences. After administering and evaluating learning style preference and brain hemispheric preference tests, the professor uses teaching strategies that address visual, auditory, tactile, and kinesthetic preferences as needed for the specific class. Both projects and writing also are incorporated into the course. Students complete journal assignments under the guidance of a writing center instructor, who uses a system of check marks to evaluate students' thinking and to assign extra credit points.

Method. The professor and the writing center instructor collaborated to develop course objectives that required higher-level thinking and learning. Among these higher-level objectives were:

- Analyze and synthesize Fibonacci Sequences by creating original artistic designs incorporating them.
- Demonstrate understanding of symmetrical properties by designing a small project using symmetrical properties found in Arabesque art.
- Construct various snowflakes using mathematical sequences to develop them.
- Use complex numbers to develop an advanced fractal, such as the Mandelbrot fractal.
- Differentiate among various graph trees, graph paths, and graph circuits by analyzing situations, choosing the appropriate structure to illustrate each situation, and correctly constructing the structure.

As usual, students' preferred learning and information-processing methods were assessed and accommodated during instruction, and they received three sets of three journal writing assignments during the semester. Some of the assignments were restructured to require more critical thinking than previously. One-minute papers were used to test students' understanding, identify any misconceptions, and stimulate engagement with the material. Tests, journals, and projects were used to assess students' learning, and students completed a survey about their achievements, experiences, and attitudes at the end of the semester. Although a final survey has been used in the past, it was revised to include questions relating to the levels of learning at which students felt confident regarding four major course topics: Fibonacci Sequences, symmetry, fractals, and graph theory.

Results: One-Minute Responses. The first one-minute response, administered early in the semester, asked students, *What was the most important point [of today's lesson]?* Twenty two students from Sections 1 and 2 responded. Designed primarily to pinpoint students' misunderstandings or lack of understanding or paying attention, this traditionally-asked question did elicited one response hinting that higher cognitive processes were at work: "The most interesting thing and important is the steps, we can use math in design. Photoshop makes our life easier however fractals are here to make [us] understand how it works" (Student BC).

Another one-minute response paper was written more strategically to encourage critical thinking. Issued only in Section 3, this question asked, *As a designer, how could you use information from today's lesson?* Four students responded. Two responses were vague: "I can maybe apply it to my final maths project or even in my senior thesis project for interior design" (Student RD), and "It can help me with my third project" (Student HA). A third response began moving in the direction of critical thinking, as it showed the student was considering possibilities for using the lesson material: "Creating beautiful fractals and being able to have several of the same one different colors because of the mathematical formula" (Student WA). Although this student was imagining working with fractals (the *Applying* stage in Bloom's Taxonomy), we could not tell whether the student was mentally moving forward to a *specific* application. From this response, we did not even know the student's design field. Unlike the other responses, the fourth one demonstrated the analysis and evaluation characteristics of critical thinking: "The use of fractals on fabric hasn't been done justice, so if used on fabric on modern day runways it would be amazing to witness" (Student HD). In this response, the student analyzed his personal design field (fashion) and evaluated current uses of fractals on fabrics, deciding they had greater potential than textile designers currently recognize. The student went beyond this realization to imagine using fractals differently or more extensively in textile design and again evaluated the anticipated effect ("amazing to witness"). Possibly (but we cannot tell for certain) the student even moved into the *Creating* level of Bloom's Taxonomy by mentally imagining his own design and how it could differ from currently known uses and designs.

Students educated in the region during their elementary and high school experiences with whom the author has worked in the past often seem deficient in meta-cognitive skills. Consequently, one of the one-minute responses focused on this type of thinking. Five students from Section 3 responded to the question, *How do you feel about your understanding of today's material?* Of these five, four wrote statements beginning with *I <u>understand</u> what x means* or *I <u>learned</u> that . . .* and gave no information about their feelings. The fifth student, however, responded somewhat clearly and appropriately: "I'm still not sure about the visual application of the complex numbers in the graph. How does it turn (that organic) => visually?" (Student A. Al-N.). This student not only expressed feelings of uncertainty but also specified what was causing them (the result of self-analysis) and demonstrated confusion in the statement itself, providing information the professor needed to aid the student.

Results: Journal Assignments. Nine journal assignments given in three sets of three assignments each were given at the beginning of approximately each third of the topics covered during the semester. The first assignment in the first set intended to stimulate students' meta-cognitive and analytical skills using their individual *Super Links.* (A *Super Link* is the combination of a person's learning style preference with his/her brain hemispheric preference, and appealing to one's Super Link in the way information is presented and processed is the quickest, easiest way for that person to learn[8]. Preference assessments were administered and discussed during the first week of the semester, so students knew their Super Links.) The assignment read as follows:

> **1. Learning Styles & Hemispheric Preferences ("Super Links")**
>
> Observe the teaching of any one of your professors **except** Dr. Schmeelk during <u>two class</u> <u>periods</u> and note what he/she does that fits in with your preferred learning style and hemispheric preference. Use the same professor for both class observations. In your journal discussion about this experience,
>
> - state your preferred learning style and hemispheric preference,
> - identify what the professor did to appeal to your "Super Link" (or failed to do if that is the case), and
> - discuss alternative things the professor could have done to appeal to your "Super Link."
>
> To get credit for answering this question, you must include answers to all three topics in your writing.

Table 1 below shows the assessments of students' responses to this assignment. Students received extra credit points ranging from one to three (see Column 1) if they turned in an answer to the assignment. If they turned in a journal without a response for the specified assignment (Assignment 1.1 in this case), they received no extra points for that assignment. If the journal were not turned in at all, students received -1 points. Of 36 students in the three sections, 23 students (63.8 percent) completed the assignment and received points for it. Ten of the 23 respondents' answers (43.5 percent) were exceptionally good, meaning that they observed, applied their new knowledge of Super Links to their own learning, analyzed what was aiding or hindering their individual Super Links, and proposed alternative behaviors to remedy the problem. These students not only succeeded in analyzing and evaluating their situations but also in thinking critically and creatively to suggest solutions.

Rating	Assignment 1.1 No. of Students, Section 1	Assignment 1.1 No. of Students, Section 2	Assignment 1.1 No. of Students, Section 3	Totals per Response
✓- (0 points)	0	0	0	0
✓ (1 point)	2	3	2	7
✓+ (2 points)	2	3	1	6
✓++ (3 points)	6	4	0	10
No Journal (-1 point)	2	2	9	13
Total Responses	12	12	12	36

Table 1. Assessments of Fall 2010 Students' Responses to Journal Assignment 1 (in Set 1 of Three Sets)

Typical of these exceptional responses were the following excerpts from a lengthy response written by Student C.A., whose Super Link exhibited a visual learning preference with a left brain hemispheric preference.

> In surface research, . . . we had to experiment with square 'planes' of different sizes: 3/4-inch, 1.5-inch and a 2.5-inch squares. They were to be arranged according to the emotions listed on the page [Professor X] gave us so that was easy for me to remember because he provided written instructions for us to look at. . . . Sometimes before starting a project, the professor gave us a preview of what is expected, enabling me to know what I must do to complete it. Previously, I had trouble in understanding the tasks given because they were only given and explained verbally, which made myself write down the task in my planner. Even if after doing that I was still confused, I . . . asked questions to clear everything up and reconfirm as to what I have to do. By then I began to visualize in my mind how the finished project should be. . . . takes up a lot of time to complete. This made me have to find a good environment to work in; therefore, I went to the VCUQ library in the weekend. . . .
>
> . . . there was a 2nd part to it where images of the emotions were to be used. . . . Once that section of the project was finished, we were all explained the layout and the importance of experimenting. I sort of did not understand it fully due to the abstract explanation. The example of what is expected from [the] task (the end result) was not given, therefore I had trouble in imagining it.
>
> . . . Perhaps [Professor X's] listing some aspects that are required in critical discussions and critical speaking so that it is easy to remember what to talk about during those sessions? (OR I should do that myself . . .) It would be helpful in order to make us well prepared for the portfolio presentation in the following year. . . . doing things that my Super Link would prefer, such as taking notes when [Professor X] is explaining so that I can understand what to do.

Throughout the discussion, this student exhibited meta-cognition and analysis/evaluation of what was happening, which are examples of the higher stages of learning involved in critical thinking. Of particular note is the last paragraph where the student abruptly moved from suggesting things the professor might do differently to enhance learning to realizing her own ability and responsibility to convert incoming information into forms she could use more advantageously. The student undoubtedly moved into the highest learning stage, creating, as she began developing strategies to facilitate her newly discovered personal power.

An example of a journal assignment designed to facilitate achieving the course objective, "Analyze and synthesize Fibonacci Sequences by creating original artistic designs incorporating them," is Assignment 2 of Set 1:

2. Using Fibonacci Numbers

Using a series of no more than three consecutive Fibonacci numbers,

- design the pattern for a brick wall using bricks to represent the numbers OR
- design a pattern for fabric using one geometric shape of your choice to represent the numbers and explain
  (1) how you are using the bricks or geometric shapes to represent each of the three numbers AND
  (2) how your pattern fits the Fibonacci sequence.

Sketch your wall or fabric in your journal and add color if you like.

This assignment first required students to select and represent three Fibonacci numbers graphically and then convert the new representations into a pattern. These activities required that students think both critically and creatively to complete the assignment. Table 2 below illustrates the evaluations of students' work on this assignment.

Rating	**Assignment 1.2** **No. of Students, Section 1**	**Assignment 1.2** **No. of Students, Section 2**	**Assignment 1.2** **No. of Students, Section 3**	**Totals per Response**
✓- (0 points)	2	2	0	4
✓ (1 point)	2	4	2	8
✓+ (2 points)	0	0	0	0
✓++ (3 points)	6	4	1	11
No Journal (-1 point)	2	2	9	13
Total Responses	12	12	12	36

Table 2. Evaluation Results of Fall 2010 Students' Responses to Journal Assignment 2 of Set 1 of Three Sets

Refer to Appendix A for sample responses students made that illustrate their analytical and creative thinking. This time 19 (82.6 percent) of the 23 students who turned in journals responded. Once again, the majority of respondents completed the assignment exceptionally well.

Results: Final Survey. Question 9 on the survey issued to students at the end of the semester intended to discover whether the learning objectives had been achieved for each of four key topics: Fibonacci sequences, symmetry, fractals, and graph theory. One or more choices under each topic matched one of the critical thinking course objectives stated on Page 5. These choices are highlighted in blue in the topics column of Table 3 below. (This column contains only the first several words in each choice for identification.) The instructions given for answering this question were: *For each topic below, please check the ONE ITEM that BEST fits the most complicated thing you feel confident about doing if someone asked you to do it.* Despite the emphasis on choosing one item, several students chose more than one item for some topics.

Topics	No. Students, Section 1	No. Students, Section 2	No. Students, Section 3	Totals per Response
Fibonacci Sequences				
Define and identify	3	6	2	11
Use recursive/explicit formulae	3	1	1	5
Identify artistic designs	2	3	1	6
Analyze and synthesize	3	3		6
Symmetry				
Define and identify	4	2	2	8
Distinguish between	4	4	1	9
Demonstrate understanding of		6	1	7
Fractals				
Define and identify		2	1	3
Explain the mathematical		1		1
Construct various snowflakes	7	5	1	13
Use complex numbers to	1	4	1	6
No response			1	1
Graph Theory				
Define and identify			1	1
Demonstrate understanding of	1	4		5
Illustrate data using	5	2	2	9
Differentiate among	2	5		7
No response	1		1	2
Total Students Responding	8	11	4	23
Total Responses Per Section	*36	*48	16	100/100

*Four extra responses were received from students who checked more than one statement per topic
NOTE: Items in blue reflect specific critical thinking objectives established for the course.

Table 3. Survey Results Indicating Students' Responses to Highest Level of Learning Per Topic

Table 3 shows that 39 percent of the responses selected one of the course objectives, which were the five statements that addressed the higher learning levels of analyzing, evaluating, and creating:

- Analyze and synthesize Fibonacci Sequences by creating original artistic designs incorporating them.
- Demonstrate understanding of symmetrical properties by designing a small project using symmetrical properties found in Arabesque art.
- Construct various snowflakes using mathematical sequences to develop them.
- Use complex numbers to develop an advanced fractal, such as the Mandelbrot fractal.
- Differentiate among various graph trees, graph paths, and graph circuits by analyzing situations, choosing the appropriate structure to illustrate each situation, and correctly constructing the structure.

More responses (13) expressed confidence about the third objective, *constructing various snowflakes*, than about any of the other objectives.

Sixty-one percent of the responses chose statements describing the lower learning levels, such as remembering, understanding, and applying.

Results: Final Project. Sample projects were used throughout the semester to help students visualize mathematical concepts and possibilities for their application. In lieu of a final examination, students were required to submit their own original projects focusing on the mathematical topic of their choice. This was the final test of students' critical thinking development (valued at 40 percent of the course grade), and they were encouraged throughout the semester to be selecting, planning, and developing their projects.

Thirty-four of 35 students remaining in the course by the end of the semester (97 percent) submitted final projects with an accompanying brief report explaining the relationship between the project and the mathematical topic. The projects and report were evaluated for mathematical development; creativity that expanded/illustrated/explained the math used in an original, unique way; artistic design; and major grammatical elements, such as clarity, thesis, and correct spelling. This semester the projects were particularly well-crafted and innovative, ranging from an origami pyramid that took a month to construct to string art designs to a Fibonacci shelf.

Discussion

So far, one-minute responses have revealed little of students' critical thinking processes, even when the prompts were strategically developed to elicit this information. We attribute the thinking level indicated by Student B.C.'s perceptive response to previous instruction and experiences rather than to the influence of instruction in MATH 131, as this response occurred too early in the semester to have resulted from our efforts. Having only one of four students answer the "feeling" prompt appropriately was disappointing, but it confirmed the author's previous experiences with some students' difficulty in realizing feelings when writing reflection papers for English classes. More attention needs to be paid to developing a series of prompts that addresses the analyzing, evaluating, and creating processes of critical thinking in addition to the standard prompts used to identify students' misunderstandings, attitudes, etc.

Although some of the journal assignments were structured to stimulate critical thinking, some students failed either to complete those assignments or to turn in a journal. Deducting points for a missing journal or giving no points for a writing assignment omitted from a submitted journal did not sufficiently motivate all students: a more effective means of evaluating and grading the journals needs to be developed. So far, Student C.A.'s realizing personal responsibility is a highlight of the journal responses requiring critical thinking. Ways to elicit more of this type of development need to be examined in future studies.

Because journal responses can give important insight into students' thinking, providing opportunities for two-way feedback between student and professor, student motivation to write the assignments and turn them in needs to be improved. One possible way to accomplish this may be through tying some test questions to the journal assignments, causing students who do not complete their journals to lose points two ways rather than one. In addition, including test questions that coordinate with specific journal assignments could reinforce learning through repetition and required recall.

The early-semester testing, instruction, and emphasis on students' Super Links focuses on self-awareness and meta-cognition, which often are underdeveloped among these students. Yet, these abilities are essential in some analyzing and evaluating, making them likewise important in the development of critical thinking. Consequently, developing self-awareness and meta-cognition should be added as course objectives.

Perhaps another evaluation tool should be introduced to measure students' improvement in critical thinking in this course. This tool could be a pre-test administered during the first week of class to assess students' initial abilities and to provide a baseline against which later efforts could be measured.

In the final survey, although the finding that 39 percent of the responses involved higher-level thinking processes is a start, it is far below a desirable percentage of self-confidence in students' cognitive skills. Possibly, the low percentage results from reading and interpretation problems that non-native speakers had with this question. Perhaps entries in Question 9 need to be restated in simpler terms or restated using terminology from Bloom's Taxonomy (remembering, understanding, etc.) in addition to the course objectives. Other possibilities may be that students ranked their confidence at lower cognitive levels because their *confidence* is low rather than their critical thinking skills, or perhaps they fear being asked suddenly to perform the action they have marked on the survey. Regardless of the reason, the survey results suggest the need to improve both meta-cognition and critical thinking skills.

As might be expected of design majors, most students responded quite well to the final project assignment. Many of the students are gifted artistically and creatively. The final project requires considerable higher-level thinking, but perhaps it should be developed in more structured, guided stages to better reinforce student's recognition of the cognitive stages involved as they move through them.

Conclusions

As the title of this paper states, this is a *preliminary* investigation, and much work remains to be done. Among recommended changes for future courses are the following:

- Introduce a course pre-test to assess students' initial critical thinking abilities and to provide a baseline against which later efforts could be measured.
- Develop additional one-minute prompts that address critical thinking processes and students' meta-cognition in addition to the standard prompts used to identify students' misunderstandings, attitudes, etc.
- Restructure the use and evaluation of journal assignments to elicit greater student motivation to complete them.
- Include test questions related to the journal assignments in exams.
- Research ways to elicit the development of personal responsibility through critical thinking.
- Add course objectives for developing students' self-awareness and meta-cognition.
- Revise the final survey using simpler terms and terminology from Bloom's Taxonomy.
- Use more structured and better guided stages in students' development of final projects.

Despite some problems, there is a sense that the strategies tried in this preliminary investigation are improving some students' knowledge and skills. A foundation for developing students' critical thinking is being laid, and we now need to find ways to enhance it.

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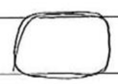
APPENDIX A

Students' Creative Responses to Assignment 1.2

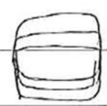
Response of Student A. Al-N.

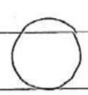
2. Using Fibonacci Numbers

I created a module using 3 shapes each Shape/line is repeated in the Number of fibonnacci sequence 1, 2, 3

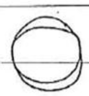


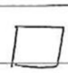
This Shape's outline is repeated 3 times creating the following form





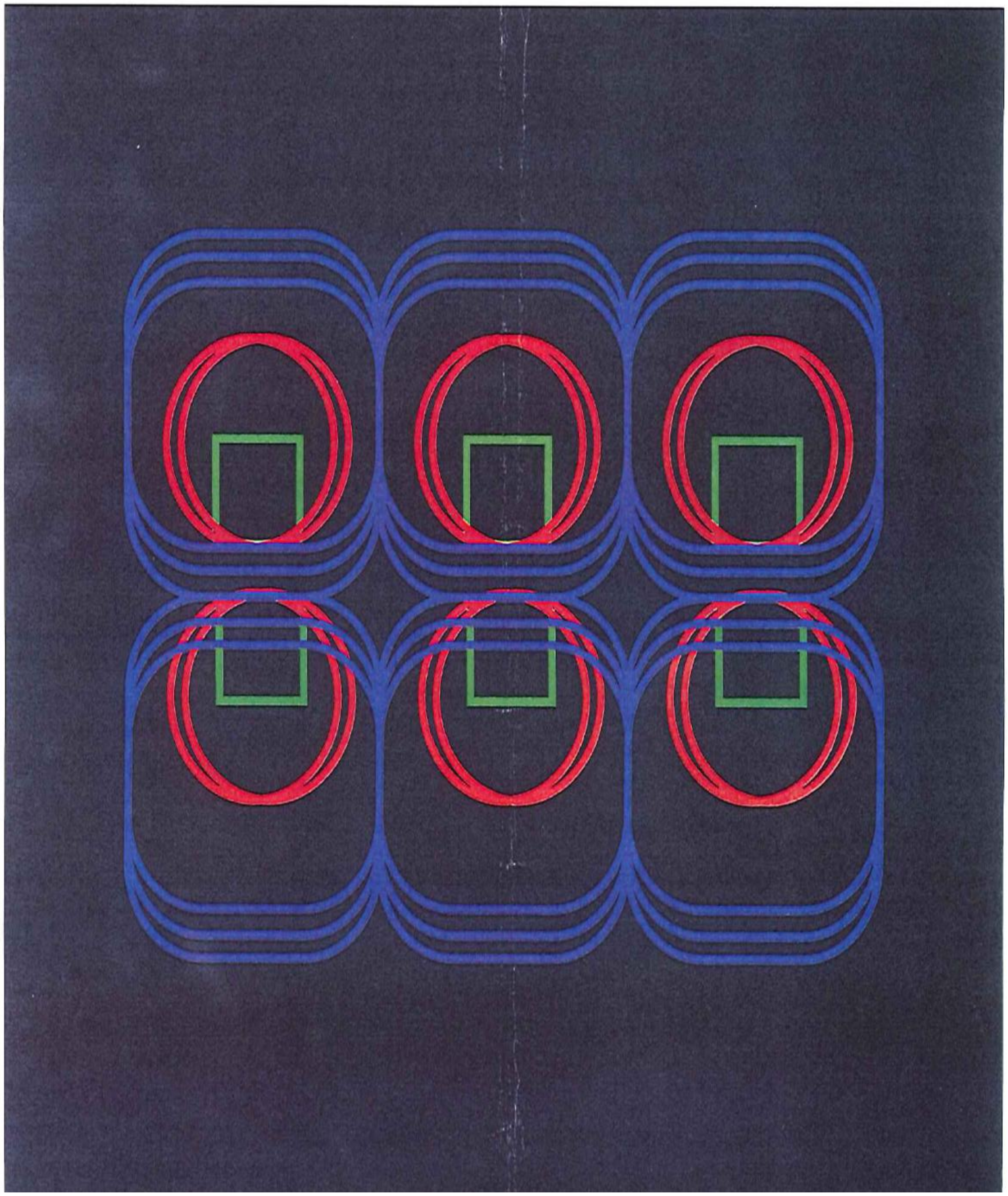
This is repeated twice 2 to creat The following form





This I've kept it singular to represent The Fibonaccia number 1

Then combining these elements to create a module That I've then used it & repeated it to creat a pattern.



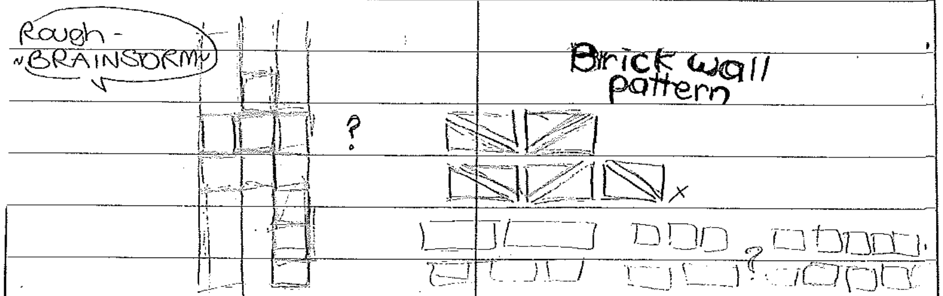
Response of Student C. A.

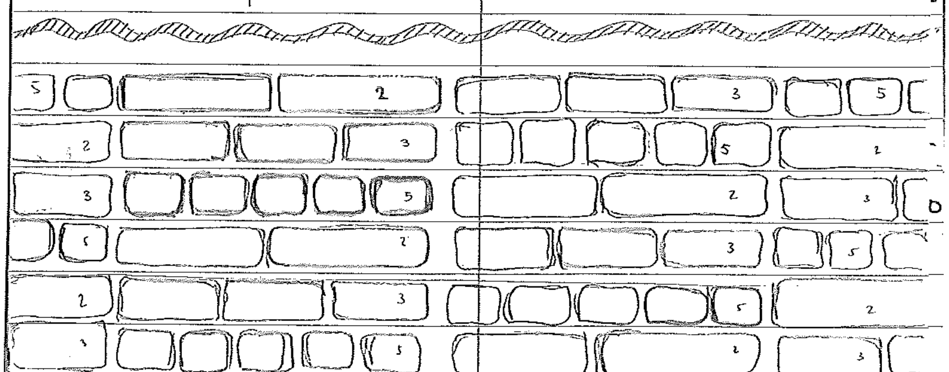
0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, ..

design patterns

② Using Fibonacci Numbers

three consecutive Fibonacci numbers: 2, 3, 5





① How are you using the bricks to represent each of the three numbers?

→ I first started off with 2 as the first consecutive number and made the brick size wider than the ones for 3 and 5. In order to keep them aligned, the

GOOD THINKING!

⑤

sizes of these bricks were altered so that even when the pattern is for a brick wall, ~~fibonacci~~ the concept of fibonacci can still be used within it. Since it is a pattern, the consecutive numbers keep repeating as it goes vertical or horizontally. The fibonacci sequence of 2, 3 and 5 is kept within the pattern and is repeated once the bricks reach the number 5. Once it reaches that number, the next amount of bricks would be 2. This concept, of course, would not apply to the original Fibonacci sequence but in this case, it would.
→ The brick size to represent the 3 is slightly smaller than the 2nd one while the 5 is broken down into 5 small bricks, representing the number.

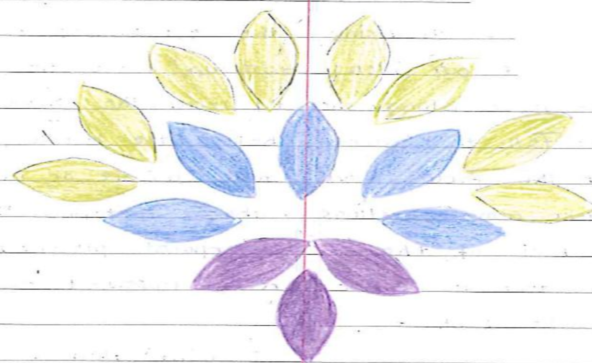
② How does the pattern fit the fibonacci sequence?

The pattern fits the fibonacci sequence because the three consecutive numbers of 2, 3, 5 gradually add up to each other and is repeated as in a pattern.

⑥

Response of Student C. C.

USING FIBONACCI NUMBERS

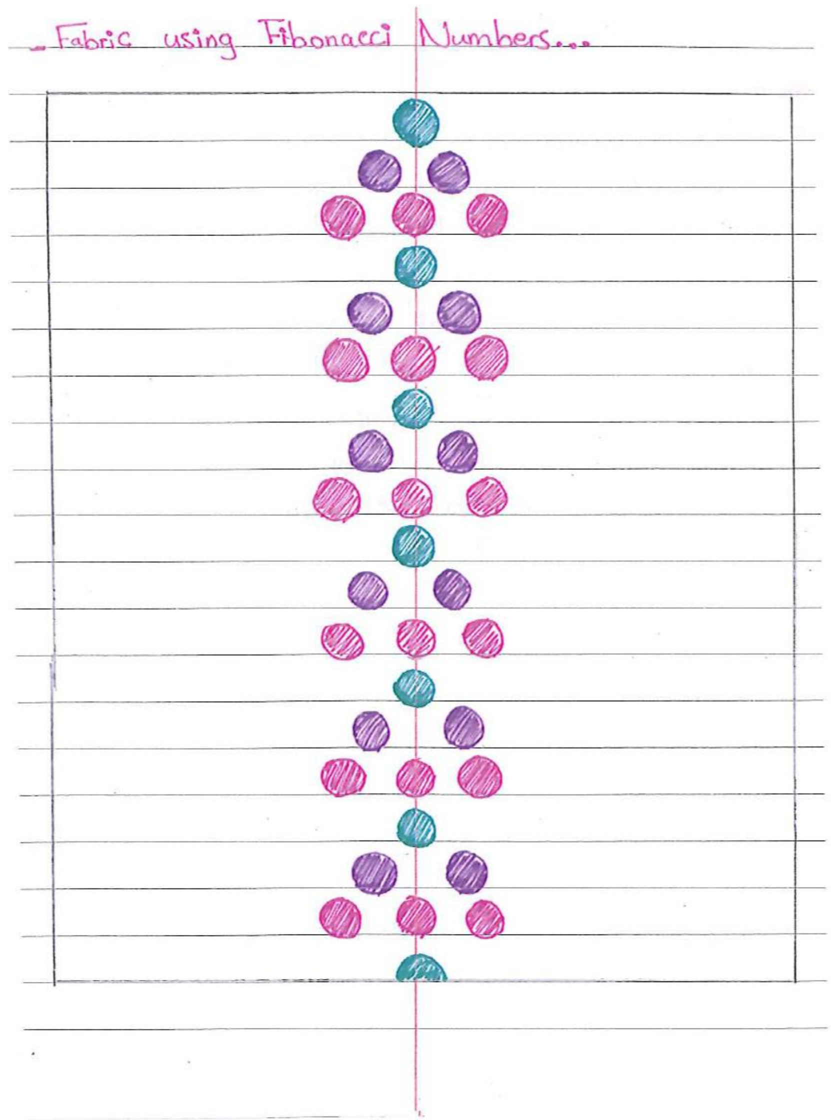


As you can see, I use the three consecutive Fibonacci numbers 3, 5 and 8. I used these numbers to design a fabric pattern. I designed these oval diamond shapes in an increasing manner that start from the bottom up.

I ovals that are colored in purple represents 3, blue represents 5 and green represents 8 as those are the numbers of the respective colored ovals.

My pattern fits the Fibonacci sequence in a way that the ovals are continously increasing by adding the two consecutive numbers before the missing number (3+5=8).

Response of Student M. A.



- The circles in the fabric represent a Fibonacci sequence. As I chose the sequence "1, 2, 3", each colored circle represents a number. For the first raw, the blue circle represents number "1". Then, for the second raw the two purple circles represent number "2" in the Fibonacci sequence. Finally, the third raw has three pink circles which represent number "3". The pattern keeps repeating. It fits the Fibonacci sequence as if you add the first two raws it gives you the third one and so on.