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Handwriting to Learn: Embedding a Crucial Study Skill in a Gateway Science Course

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Abstract. Handwriting is a multisensory process known to enhance memory, focus, engagement, and cognition in the learner, thereby making it a valuable study skill. In an attempt to embed handwriting as a study skill in a gateway science course, I used a combination of scaffolding and individual student consultations. Scaffolding emphasized the use of *desirable difficulties* and *retrieval practice* through the implementation of techniques such as the *flipped learning* approach and *take-home in-class hybrid* essay exams. While the former helped to increase overall student success, the latter technique was aimed at enhancing written fluency in the subject, curbing procrastination, and providing opportunities for high impact retrieval practice during the in-class essay exams. One-on-one student consultations that emphasized rewriting and maintaining good notes were used as interventions throughout the semester to promote positive study behavior and also as a crucial stage in preparing for each unit exam. The level of student engagement in using handwriting as a study skill was traced within the context of a typical *threshold experience*. Handwriting as a study skill was successfully embedded in this course and showed positive results in terms of student retention, engagement, and overall success.

Keywords: Handwriting, threshold experience, retrieval practice, desirable difficulties, flipped learning

Writing by hand employs many more senses in comparison to reading. Handwriting involves tactile, proprioceptive (sense of movement), visual, and spatial senses; whereas, reading employs the visual and spatial senses only. When learning new information, handwriting engages learners by directing visual focus to the tip of their pens (Fogassi & Gallese, 2004). This stimulates the reticular activating system in the brain, whose function is to prioritize sensory information that enters the consciousness and help in focusing on what is important. Therefore, when turned on during handwriting, the reticular activating system can sharpen focus and heighten attention (Kinomura, 1996). Handwriting is, in general, a slow process that involves the hand and the brain in a sensory-motor feedback loop allowing better factual recall and deeper cognitive processing (Mangen & Velay, 2010; Mueller & Oppenheimer, 2014).

The idea that learning occurs not only via cerebral processing but also via muscle/motor activity is called *embodied cognition*, a concept that is gaining enormous importance (Borghi & Cimatti, 2010; Engel, Maye, Kurthen, & Konig, 2013; Foglia & Wilson, 2013). A recent study has shown that when children used

finger tracing on an iPad to study graphs they did significantly better when tested on the understanding of these graphs when compared to children who studied the same graphs without finger tracing (Agostinho et al., 2015). Finger tracing of graphs takes advantage of embodied cognition to deepen comprehension in a way that reading graphs off a screen does not. When writing by hand, the writer graphomotorically forms each letter (Mangen & Velay, 2010) much like in finger tracing. Writing by hand is a motor activity that uses multiple sensory inputs (tactile, proprioceptive, etc.) thereby making it a readily available mode of embodied cognition for students in higher education.

In contrast, keyboarding entails hitting ready-made alphabets and is therefore faster; yet, it does not appear to benefit the learner in terms of deeper cognitive processing. In a recent note-taking study (Mueller & Oppenheimer, 2014), students who used longhand tended to retain more information and demonstrated a deeper understanding of the lecture material when compared to those who used keyboarding to take notes. They found that although students using keyboarding take more notes than those using longhand, they tend to type what they hear verbatim without deeply processing what they type (Mueller & Oppenheimer, 2014).

Note-taking has two major—storage of information that can be reviewed later and encoding of information in the brain that results in higher cognitive processing (Kiewra, 1985). This encoding function of note-taking has a positive impact on student performance with students who take notes performing significantly better than those who do not (Boyle, 2007; Boyle, 2010; Kiewra, 1985; Kiewra & Benton, 1988; Piolat, Olive, & Kellogg, 2004; Titsworth, 2001). Yet, note-taking is a very complex activity that places enormous demands on a very limited working memory. Our working memory can only hold about four units of newly acquired information at any given time and it decays within seconds if it is not rehearsed or reinforced (Cowan, 2001). If handwriting speed is slow, then information held in the working memory is quickly forgotten and the quality of note taking becomes greatly hampered. *Transcription fluency* or handwriting speed has been shown to have a positive effect on note-taking (Peverly et al., 2007) by lightening the load on working memory resources, thus freeing up some of the working memory space to address higher order cognitive processes such as comprehension and application of newly acquired information. Note-taking requires a great deal of cognitive effort because it involves listening, remembering, writing, organizing, selecting, and making connections with prior knowledge all at the same time (Piolat et al., 2004).

A subject that is complex with many interacting elements (human physiology for example) is said to have a high level of *intrinsic cognitive load*, placing high demands on the working memory of the learner (Mayer, 2005; Sweller, 1994). Coupling the cognitive demands with note-taking can hamper both comprehension and transcription. This is because the note-taker often ends up either limiting transcription to allow for comprehension or limiting comprehension to allow for better transcription (Kiewra, 1985). This predicament introduces yet another type of cognitive load called *extrinsic cognitive load* that can impede learning (Sweller, 1994). Instructors have addressed this problem by providing students with

readymade notes in the form of handouts or PowerPoint slides, a practice that deprives students of the opportunity to generate their own study materials. Students perform better when they generate their own study materials in the form of handwritten notes when compared to students who have been given readymade study materials (Mueller & Oppenheimer, 2014; Piolat et al., 2004). Alternatively, making students copy notes off a PowerPoint slide or the board does not lead to comprehension of the material (Piolat et al., 2004).

Therefore, to maximize the benefit to students, we need to uncouple, at least temporarily, the comprehension and transcription aspects of note-taking. One way to accomplish this would be to scaffold the learning process into several stages to provide adequate time and working memory resources for both comprehension and transcription to occur. Scaffolding can help to minimize extrinsic cognitive load by presenting concepts in a way that is not distracting or overwhelming to the learner and manage intrinsic cognitive load by providing multiple opportunities for students to grasp the material in stages while monitoring their understanding. Adopting the *flipped learning* format can effectively address intrinsic cognitive load (Akkaraju, 2016).

Apart from effective note taking in the classroom, it is equally important to maintain accurate and complete notes aligned to each learning outcome listed for a particular topic. Rewriting class notes by hand in a separate study notebook can serve both as an excellent external storage of study materials and as a highly effective learning tool. Adopting a *take-home in-class hybrid essay exam* format is one way to motivate students to rewrite class notes, align them to learning outcomes for a specific topic, practice drawing diagrams and flow charts wherever appropriate, and feel confident about their understanding of the material.

The flipped learning approach and the take-home in-class hybrid essay exam introduce a number of *desirable difficulties* for the learner. A *desirable difficulty* is a strategy that helps the learner to experience deeper cognitive processing and achieve lasting retention by initially slowing down the learning process and making it deliberately harder for the learner. However, the learning strategy cannot make it so difficult as to discourage the learner (Bjork, 1994; Brown, Roediger, & McDaniel, 2014; Marsh & Butler, 2013). The task must be difficult, but accomplishable. For example, re-reading one's notes is easier than re-writing one's notes with the latter being a desirable difficulty because it is both more time-consuming and memory enhancing than the former. With the in-class portion of the essay exam, students are expected to provide detailed and often lengthy answers to essay questions. *Retrieval practice* is a type of desirable difficulty, known to significantly increase long term retention and meaningful learning. Answering essay questions on an exam is a powerful form of retrieval practice (Karpicke, 2012; Roediger & Butler, 2011; Roediger & Pyc, 2012).

To successfully embed a study skill in a course, it helps to track student experience and uncover any problems that the student might be facing. One way to approach this would be to view this skill acquisition process in terms of a *threshold experience*, which is a fundamental aspect of the *threshold concept theory* (Meyer &

Land, 2003). A *threshold concept* is a doorway that leads to an entirely new way of thinking about something, resulting in a shift in perception. A threshold concept is both troublesome and transformational. It is troublesome because it is difficult or perhaps counter-intuitive; it is transformational because it results in a paradigm shift in perception. According to Meyer and Land, in order to master a threshold concept in any subject, the student must enter a *liminal space* in which the student deeply engages with the concept to master it. However, this learning process is rarely linear as the learner oscillates between *excursive* and *recursive* journeys (Land, Cousin, Meyer, & Davies, 2005). During the excursive journey, the learner takes bold steps towards tackling the challenging concept; whereas during the recursive journey, the learner gets stuck or returns to areas of confusion. The learning process involved in mastering a threshold concept is called a *threshold experience* (Meyer & Land, 2005). Even though threshold experiences were originally meant to only describe the mastery of threshold concepts that are theoretical, more recently some authors have proposed the inclusion of *threshold skills* in this category (Thomas et al., 2017). In this article, I refer to a threshold experience set in the context of students acquiring a threshold skill. When observing students undergoing a threshold experience, those students who are unwilling or not yet ready to engage with the study skill are said to be in the pre-liminal stage; those that engage with the study skill are said to be liminal; and those that have truly mastered the skill are said to be post-liminal. Therefore, it is very useful to regard student experience of acquiring a study skill as a threshold experience. In this way, it is easy to identify the pre-liminal learners and reach out to them. Consultations with students can help to emphasize the importance of rewriting notes and positively influence future study behavior (Huijser, Kimmins, & Gallager, 2008).

In this article, I describe: (a) how I scaffold the learning process to maximize comprehension and allow opportunities for unhurried, effective note-taking by hand; (b) how I scaffold the take-home in-class hybrid exams to promote the use of handwriting as a study skill, increase transcription fluency, curb procrastination, and provide opportunities for powerful retrieval practice; (c) how I track student progress in the context of a threshold experience and use student consultations to reinforce positive study behavior; and (d) how embedding handwriting as a study skill can significantly improve student engagement and overall performance.

Methods

This study was conducted in Bronx Community College of the City University of New York, where 98% of the students are ethnic minorities with 90% of the students needing at least one remedial course. Handwriting to learn was implemented for four consecutive semesters in the lecture session of an undergraduate human anatomy and physiology I course with a typically low retention and passing rate. The overall pass rate (passing with at least a D- or 60%) for this gateway science course is typically 60% and the retention rate for this course is 70%. A total of 90 students were enrolled in all four sections. However, a total of 10 students withdrew and therefore the overall results presented here are based on a sample

size of 80 students. On the first day of class, all students were asked if they used handwriting as a study method, and at mid-semester they were asked to respond to a survey on their study methods in general and how they view the use of handwriting to learn in particular.

Handwriting to learn was embedded in the course by meticulously scaffolding the learning process and by viewing the skill acquisition process as a threshold experience.

Scaffolding the Learning Process

The scaffolded design of the flipped learning format was aimed at enhancing comprehension and note-taking (Table 1). The scaffolded design of the take-home in-class hybrid exam was aimed at enhancing transcription fluency, creation of good study notes, curbing procrastination, and providing opportunities for high impact retrieval practice (Table 2).

Table 1.

A scaffolded design of flipped learning to maximize comprehension and note-taking

Rationale	Student Learning Outcome *"Student will be able to…"*	Teaching Technique	Learning Opportunity
Enhances comprehension	Demonstrate mastery of factual knowledge and basic conceptual knowledge prior to engaging in higher order information processing	Flipped Learning	Learning module made available to student before class followed by a Pre-Lecture Quiz at the start of each lecture session
	Demonstrate understanding of conceptual knowledge prior to note-taking	Socratic Method	Students answer questions throughout the lecture and are instructed *to not* take notes
	Apply conceptual knowledge to solve problems	Active Learning	Students are asked to solve problems in groups
Enhances effective note-taking	Take notes that are complete and accurate.	Socratic Method	The concept is developed again on the chalk board in a step wise manner and the students are actively engaged by providing answers to "*What comes next*?" or "*What happens if*?" before writing down these steps by hand.

During a typical lecture session, the students would take a pre-lecture quiz at the beginning of class. The pre-lecture quiz, which was worth 20 points, was simple and straightforward with the goal of assessing the students' grasp of factual knowledge. Together, we then reviewed the correct responses for all 20 questions. The students were now primed to receive conceptual knowledge.

Table 2.

A scaffolded design of the take-home in-class hybrid exams to curb procrastination, generate study guides, enhance transcription fluency, and provide opportunities for retrieval practice.

Stages of the hybrid essay exam	Rationale	Student Learning Outcome	Assessment Vehicle
Stage I: Students are given about 12 essay questions as a take-home exam. They are encouraged to work in groups	Curb procrastination	Student will be able to rewrite, organize, and align lecture notes with the essay questions listed in the take-home exam.	Handwritten early drafts of take-home exam
Stage II Students present their answers for feedback before the actual deadline.	Generate study guides		
Stage III: Students are instructed to practice rewriting their essays and re-drawing illustrations before they sit for the unit exam	Enhance transcription fluency	Students will be able to demonstrate a high degree of transcription fluency	In-class exam
Stage IV: Students take the unit exam, which is a combination of multiple-choice questions (50%) and essay questions (50%)	Provide opportunity for high-impact retrieval practice	Students will be able to provide answers to essay questions that are relevant, accurate, sufficiently detailed, and accompanied by illustrations wherever appropriate.	

Using the Socratic method of questioning, waiting for student response, and monitoring student understanding, the concept was developed in the students' minds using one or two visuals. During this period, the students were instructed to not take any notes; instead, they were asked to "*just relax and listen*". More precisely, they practiced "active listening" as they were continuously prompted to answer questions and encouraged to clarify understanding with questions of their own. The concept was repeated two or three times in this way using an increasing number of prompts in the second and third rounds. At this point, the students were ready for note taking. Rather than merely copying or transcribing notes off the chalk board, we developed the concept or physiological process on the board together. The students paused to answer questions such as "*What comes next?*" or "*What would happen if*?" before the responses to these questions were written on the board to allow for both comprehension and transcription to occur. A total of four

take-home in-class hybrid essay exams were given during the course of the semester. Three out of four of these exams were given as unit exams and served as benchmark assessments to provide ample feedback to the student and allow for metacognitive thinking regarding the students' own performance. The last exam was comprehensive and served as a summative assessment for the lecture portion of the course.

Table 3.

A sample of essay questions that appear on a take-home exam

Essay Question	Designed to Assess student ability to….	Skills involved
Draw two flowcharts showing how the body adjusts to maintain constant body temperature specifying the stimulus, receptor, control center, effector, and response—(a) when the body temperature rises above normal on a hot day; (b) when the body temperature drops below normal on a cold day	1. Describe a process 2. Use key terms correctly 3. Recognize subtle yet important differences in the two examples	Drawing a flow chart
Draw a table and list the four biological macromolecules, specify the functional groups found in each, building blocks for each, and list the subclasses for each macromolecule or draw a detailed mind map to represent the same information.	1. Classify and organize information 2. Recognize subtle yet important differences between molecules 3. Use key terms correctly	Making a table or creating a mind map
Show the formation of the bonds that hold NaCl and $CaCl_2$ together using drawings. Specify the type of bond that is formed here and the changes in charge that occurs.	1. Describe a process 2. Display logical reasoning 3. Use key terms correctly	Drawing molecular structures to illustrate a process
Draw diagrams to explain what happens to KCl in the presence of water	1. Describe a process 2. Display logical reasoning 3. Recognize subtle yet important differences between molecules 4. Use key terms correctly	Drawing diagrams to illustrate a process
Draw the electron arrangement in the following molecules: H_2O, CH_4, O_2, and H_2. Specify the type of bond that is formed in each case.	1. Describe a process 2. Display logical reasoning 3. Recognize subtle yet important differences between molecules 4. Use key terms correctly	Drawing molecular structures to illustrate a process

A typical unit exam consisted of both multiple choice and essay questions, with each portion taking up 50% of the total points for the exam. To stay within the topic of handwriting to learn, I will only be referring to the essay portion of these

unit exams. Each exam was scaffolded into separate stages (Table 2) to allow for maximum preparation on the part of the student. A list of 12 to 15 essay questions are provided to the student one month prior to the unit exam and the students are expected to complete answering these questions prior to the actual date of the unit exam (Table 3). Students were encouraged to work in groups and help one another in this process. On the exam day, the students were expected to submit their take-homes and sit for the exam. Four to six questions from this take-home question set appear on the actual exam, and the student is expected to answer them without the aid of their notes or text. Hence the term *take-home in-class hybrid exam*. The expectation is that the answers would be relevant, accurate, possess the right amount of detail, and include illustrations, graphs, flow charts, or concept maps wherever appropriate.

Table 4.

Rubric used to assess take home and in-class exams

Criteria	Ready for the Final	Needs a little work	Needs a lot of work
Completion	Student has successfully completed all 12 essays Subparts of all questions have been answered to completion	Student has successfully completed 8–10 essays Subparts of most of the questions have been answered to completion	Student has successfully completed 0–6 essays Subparts of many questions have not been addressed to completion
Comprehension & Relevance	Demonstrates firm understanding of main point in all essays	Demonstrates firm understanding of the main point in most essays	Appears to have missed the point of many of the essays
Accuracy & Logical Reasoning Relevance	Sequence of events in flow charts or logical reasoning is correct in all essays There are fewer than three factual errors There is no inclusion of unnecessary or distracting information Correct use of arrows throughout	Sequence of events in flow charts or logical reasoning is correct in most essays There are less than five factual errors There is some inclusion of unnecessary or distracting information Correct use of arrows for the most part	Sequence events or logical reasoning is incorrect in several essays. There are four or more factual errors There is a lot of inclusion of unnecessary or distracting information Incorrect use of arrows in many places
Attention to Detail	Graphs, illustrations, and keys contain no errors and they are complete	Graphs, Illustrations, and keys contain minor errors and/or exclusions	Graphs, Illustrations, and keys are incorrect or incomplete.

Typically, the essay questions on a take-home exam cover all the major concepts within the topics assigned for that unit exam. Therefore, answering these questions in a detailed and complete manner would automatically create self-generated study notes for the student. The essay questions were designed to assess student ability to describe a process, display logical reasoning, use key terms correctly, classify and organize information, and recognize subtle yet important differences between

molecules, processes, concepts, etc. (Table 3). The take-home and in-class exams were graded using a rubric that assessed relevance, logical reasoning, comprehension, accuracy, attention to detail, and completion (Table 4).

Viewing the skill acquisition process as a threshold experience for students

In the context of the threshold experience, learning occurs within the *liminal environment*, which is a nurturing environment that is created and maintained by the instructor. Within this environment is the *liminal space* in which the student may struggle with a new concept or skill and may even get stuck during this process (Land, Meyer, & Baillie, 2010). Visualizing students as being within this liminal space is very useful in identifying students that are stuck, struggling, or hesitant to engage in the learning process. Students who are hesitant to participate in the learning process are said to be *pre-liminal*. The rest of the students who are engaged, but face difficulties in the normal course of learning, are said to be *liminal*. They could be taking an *excursive journey* by fully embracing the task at hand or they could be taking a *recursive journey* by retreating from the task at hand. A student who has come out of the threshold experience after having been transformed by it is said to be *post-liminal* (Cousin, 2006).

A variety of assessments (formative, benchmark, and summative) were used to identify pre-liminal, liminal, and post-liminal students (Table 5). The pre-lecture quiz served as a weekly formative assessment. It was used to assess the quality of preparation and mastery of factual and basic conceptual knowledge at the beginning of each lecture session. Results were used to identify pre-liminal students who were either unwilling to put in the effort or hesitant to engage with the material. The take-home exam served as a monthly formative assessment. Students presented their handwritten take home essays for review and feedback throughout the four-week period leading up to the day of the unit exam. This practice ensured that their answers were complete, accurate, well-organized, and germane to the essay question. Results from this assessment were used to identify pre-liminal students who were hesitant to put in the time and effort necessary to prepare for the unit exam. The in-class exam served as a benchmark assessment. Results from this assessment were used to identify both pre-liminal students and those liminal students who were not fully engaging in the habit of using handwriting as a study skill.

One-on-one student meetings were designed to address the affective, behavioral, and cognitive dimensions of student engagement (Fredricks, Blumenfeld, & Paris, 2004) with the goal of positively influencing study behavior (Table 5). Particular emphasis was placed on the importance of rewriting notes and aligning them to each essay question, and student accountability was built in by arranging short follow-up consultations to make sure that the student was staying on task.

To get a better sense of the student threshold experience, students were asked to respond to a survey about their study habits and perceptions of using handwriting as a study skill (see Table 7).

Table 5

Student Consultations addressed different aspects of student engagement.

Addressing Engagement	Consultation Process	Purpose	Instructor prompts
Affective (Emotional)	Communicate empathy towards the student who is struggling in the course	To make student feel supported in the learning process	• What do you think is the problem? • Let's see what we can do to help you ace the next quiz… • Are you writing as you learn for the lecture quizzes?
	Encourage student to talk about long-term goals	To give the student the opportunity to self-assess level of motivation to succeed	• What is your major? • How did you choose it?
Behavioral	Ask student to show me their study notes	To assess student's preparation and their use of handwriting as a study skill	• Let's have a look at your study notes….
Cognitive	Emphasize the importance of re-writing notes and aligning them with learning outcomes for better retention	To help the student understand the importance of handwriting as a valuable study skill	• Do you have the essay questions for this topic? • Can I see your class notes? • Can you find the answers to these questions? • How many times have you practiced re-writing these essays?
	Build accountability into the student's study behavior	To help the student beat procrastination	• I want you to show me your completed take home essays next week….

Results

Overall student performance

By the end of each semester, benchmarks were met for all major desired outcomes (Figure 1). Benchmarks were set at 80% for the take home-exams and 70% for the in-class exams reflecting the level of difficulty involved in each assessment.

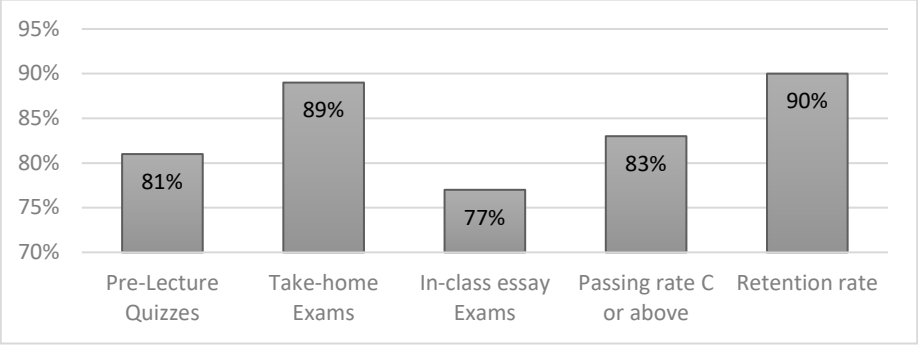

Figure 1. Students achieving benchmark in all four sections combined (n=80)

Students met benchmarks for mastery of factual and basic conceptual knowledge, note-taking, generation of study notes, transcription fluency, high impact retrieval practice, retention rates, and pass rates (Table 6).

Table 6

Assessment summary for embedding handwriting as a study skill for all four sections

Desired Outcomes	Assessment Vehicle	Benchmark	Result
Students will be able to demonstrate mastery of factual knowledge and basic conceptual knowledge prior to engaging in higher order information processing	Pre-lecture Quizzes	Overall 70% of students will score 80% or higher on the pre-lecture quizzes	81% of the students scored 80% or better on the pre-lecture quizzes
Students will take notes that are complete and accurate	Student notes	80% of the students will maintain complete and accurate lecture notes	90% of the students maintained complete and accurate notes
Student will be able to rewrite, organize, and align lecture notes with the essay questions listed in the take-home exam.	Take-home Exams	Overall 80% of the students will score 80% or better on take home exams	89% of the students scored 80% or better on the take home exams
Students will be able to demonstrate a high degree of transcription fluency	In-class Exams	Overall 70% of the students will score 70% or better on in-class exams	77% of the students scored 70% or better on the in-class exams
Students will be able to provide answers to essay questions that are relevant, accurate, with the appropriate amount of detail and accompanied by illustrations wherever appropriate	In-class Exams	Overall 70% of the students will score 70% or better on in-class exams	77% of the students scored 70% or better on the in-class exams
Improve pass rates for this course	Final Grades for this Course	At least 70% of the students will pass the course with a C or better	83% of the students passed the course with a C or better
Improve retention rates for this course	Final Grades for this Course	At least 80% of the students will remain in the course	90% of the students remained enrolled in the course

Examination of the threshold experience in a single section

The largest section with a total of 24 students was examined closely to exemplify the threshold experience. In this section, students had trouble with exam 2 for which they did not meet the benchmarks for the take-home and in-class portions (Figures 2 and 3). Only 78% of the students were able to score 80% or better on the take-home exam and a corresponding 61% of the students were able to score 70% or better on the in-class exam. However, the students appeared to regain their confidence and perform significantly better in the take-home and in-class essay portions of exam 3 and the Cumulative Final. Nearly the entire class scored 80% or better on take-home portion of exam 3, and 91% of the students scored 70% or better on the in-class portion of exam 3 (Figures 2 and 3).

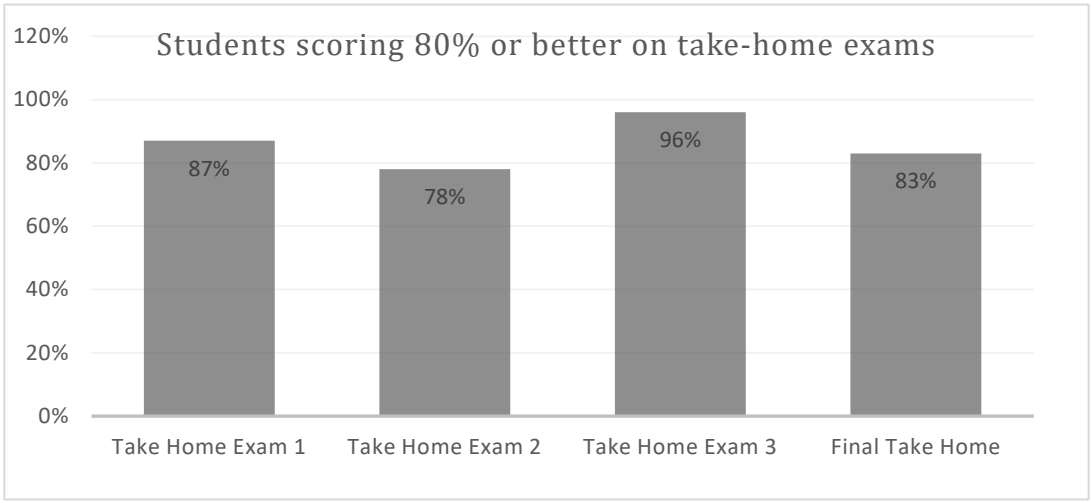

Figure 2. Student performance on take-home exams from a single section (n=24)

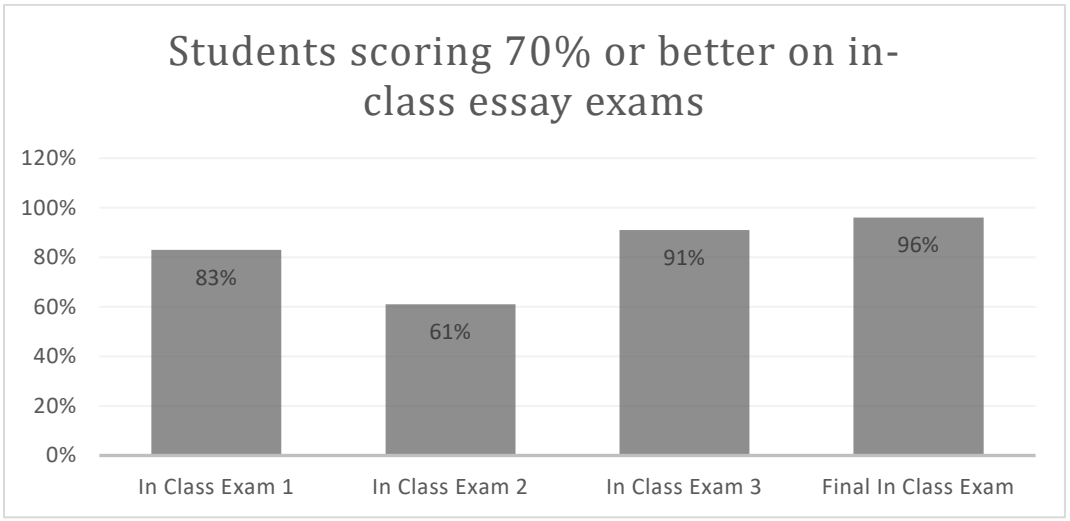

Figure 3. Student performance on in-class exams from a single section (n=24)

The grade distribution in each of these exams helped to classify the students into pre-liminal and liminal. There were those who were yet unaware of the importance of handwriting to learn or hesitant to put in the effort; these students can be viewed as *pre-liminal*. Within the liminal group, there were those who were clearly stuck or seriously struggling; these students can be viewed as being *liminal recursive*. There were those who were coping well with this study strategy and producing good results; these students can be viewed as being *liminal excursive*. This classification was extremely useful in understanding and being empathetic towards the learner's struggle in acquiring a new skill (Figure 4). Students scoring 80% or better on the in-class essay exam were classified as liminal excursive, students scoring 70-79% as liminal recursive, and those scoring below 70% as pre-liminal.

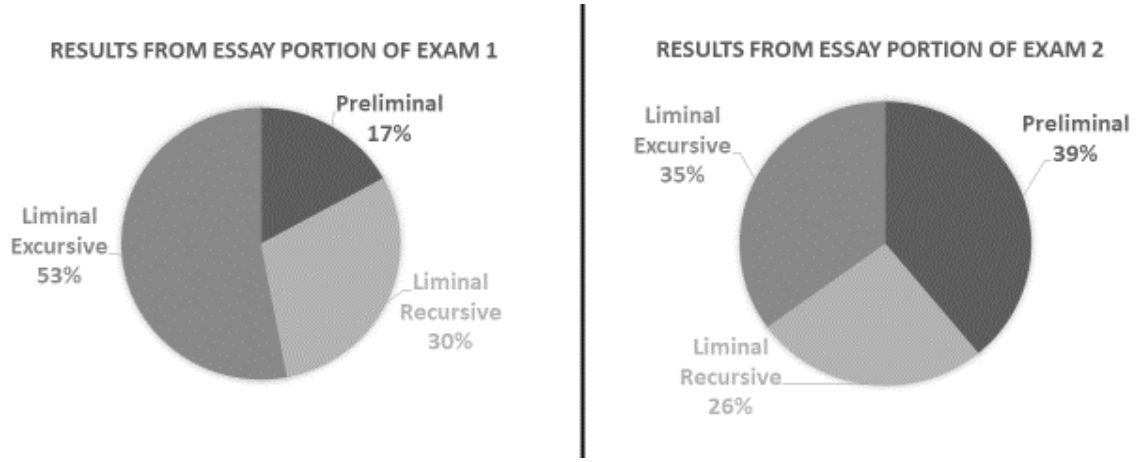

Figure 4. The percentage of liminal excursive students was low in the first two exams in this section (n=24)

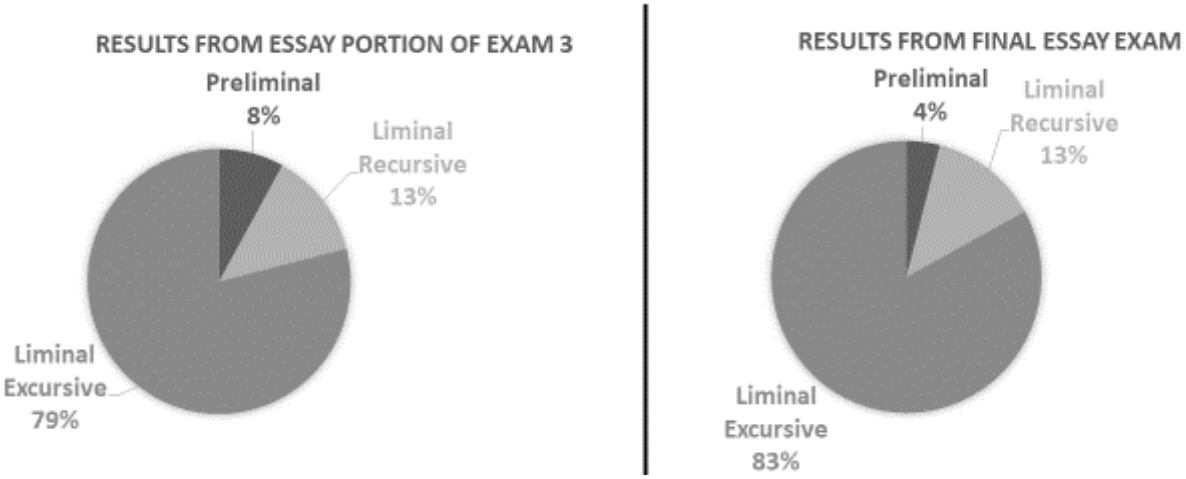

Figure 5. The percentage of liminal excursive students rose significantly on the last two exams in this section (n=24)

Following numerous interventions in the form of one-on-one student consultations, student engagement and performance significantly improved in the latter part of the semester (Figure 5).

On the first day of class, when asked about their study habits, only 17% of the students stated that they used handwriting to learn. And even those that did use handwriting to learn stated that they used it only on rare occasions. By the end of the semester, 83% of the students were successfully using handwriting to learn. When asked about the usefulness of the take-home exams in their performance, 100% of the students stated that they found it useful. This number does not include those who withdrew from the course, which was about 11%. For each lecture exam, at least 80% of the students submitted drafts of their take-home exams for feedback a week before the actual exam, thereby demonstrating their ability to curb procrastination in preparing for the lecture exam. These students also stated that they used their take home essays to study for the lecture exam.

Table 7.

Sample student reflections on handwriting to learn recorded at mid-semester

Reflection prompt	Student reflections
I believe that the take home exam helped me because…	"Those are usually hard questions, which then helps me understand them more"
	"I learn better by writing"
	"It forces me to really take the time out to study throughout my busy schedule between work and school. If I didn't have the take home, I would probably be cramming rather than taking the time needed out"
	"It helped me understand the concept we were learning much better than just writing it in class"
Until I took these take home exams I never realized that…	"Studying could be so helpful by drawing and learning everything twice"
	"It will help me a lot. It helps to organize study notes and be prepared for the exam"
	"The time and patience it takes to review all the notes and power points to figure out and answer the take home questions"
	"Actually, rewriting your notes and diagrams and definitions is a lot more effective than re-reading and highlighting things of importance"
What I don't like about take-home exams is that…	"Although rewriting is tedious, it's so helpful for memory"
	"Certain questions require a lot of information so it takes a little more time to understand and to be able to translate it back onto the exam"
	"It's very lengthy and I always have to take 2-3 hours to complete it effectively"
	"Sometimes it is stressful finding some answers"

Discussion and Conclusions

Handwriting to learn as a study skill was successfully embedded in a flipped learning section of a gateway science course. Results show that students took advantage of the desirable difficulties presented to them in the form of weekly

quizzes, take-home, and in-class essay exams. As a result, they were able to develop their note-taking ability, beat procrastination, generate their own study materials, and enhance transcription fluency. The latter was demonstrated by the generally good performance on the in-class essay exams, which were essentially high impact retrieval practice opportunities.

At the beginning of the semester only 17% of the students stated that they sometimes used handwriting as a study skill; at the end of the semester that number increased to 87%. Students not only used handwriting to learn but they were all in favor of it by the end of the semester. Even those students who were at the pre-liminal stage until mid-term were encouraged to step into the liminal space and take full advantage of this threshold experience (see Figures 4 and 5). This was accomplished by regular one-on-one consultations with the *pre-liminal* students to influence positive study behavior (see Table 5).

Students certainly struggled with the threshold skill of handwriting to learn. They found it to be troublesome due to the time commitment involved (see Table 7). Student performance in the second unit exam shows a definite recursive period during this threshold experience. Yet, in the end, 83% of the students crossed the threshold and appeared to be transformed by this experience (see Figure 5). Their excursive journey began towards the end of the semester as shown by their strong performance in unit exam 4 and continued to remain steady for the cumulative final exam (see Figure 5).

Both the flipped learning approach and the take-home in-class hybrid essay exam format appear to have had a positive effect on overall student performance and general morale of the students (see Table 6). Students met all the benchmarks set for this project including significantly improved retention and pass rates with 83% students passing the course with a grade of C or better and 96% of the students remaining enrolled throughout the course of the semester. These success rates are significantly higher than that of average pass and retention rates for this course.

Individual student consultations were not just meant for students at-risk. They also helped to curb procrastination. Before the actual date of the unit exam, about 80% of the students regularly submitted their work for feedback well before the day of the lecture exam to make sure that they were on the right track (see Table 2). This served as a sort of *guarded threshold* in which the instructor does not allow the student to enter the next stage of this threshold experience until they can demonstrate their ability to correctly answer the essay questions on the take-home exam (Akkaraju, 2015). These individual student consultations appeared to significantly improve student performance when you compare student performance in the first essay exam with the final essay exam (see Figures 4 and 5).

Student written reflections and one-on-one consultations on handwriting to learn were very encouraging. Although they found this process to be time-consuming, a few appeared to be transformed by this learning experience (see Table 7) thereby fulfilling the troublesome and transformational aspects of a typical threshold experience. In future semesters, I plan to focus more on the troublesome and

transformational aspects of adopting handwriting to learn as a study skill to understand the extent to which this experience impacts both immediate and long-term study behavior.

As an added note, a comparison of student performance in the multiple-choice portion of the exams versus the essay portion of the exams showed no correlation. This may have been because the learning opportunities provided for the multiple-choice portion of the exam were unlike the learning opportunities presented here for the essay portion of the exam. In the future, it is important to address whether or not students can demonstrate their understanding of conceptual information and apply these concepts to real life situations *as a direct result* of using handwriting to learn as a study skill.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article.

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