



Introducing Metacognition to Sophomores and Juniors and Its Effect on Academic Performance

Dr. Brett Batson, Trine University

Dr. Batson is a professor at Trine University in Angola, Indiana. His non-academic experience includes automatic controls for process turbocompressors, gas and steam turbines, and patent prosecution. His interests include mathematics education, tools and materials for supporting student learning, and general pedagogy.

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Abstract

Due to a perceived lack of academic preparation provided by U.S. high schools, an interest in teaching students about metacognition has been developing among educators at the college level.

Metacognition is an individual's awareness of his or her own learning and thinking processes. Directed to learners, it has been described as *thinking about your own thinking* [1]. Importantly, metacognition is personalized. It is not how *everyone* thinks or learns.

In the literature generated by those interested in providing metacognition intervention, significant thrust has been aimed toward first semester freshmen [1]. That approach seems appropriate, given that strategies learned early may aid students throughout their academic tenure. If, however, a student is not exposed to metacognition at the freshman level, Can such exposure still help that student?

A hypothesis of the instant work is that students at all academic levels may benefit from an understanding of their learning processes, and behaviors proven to enhance learning.

In the fall 2017 semester, students in a first semester thermodynamics course (mostly sophomores and juniors) and students in a fluid mechanics course (mostly juniors) were presented information about metacognition, roughly following the McGuire [1] model. After the first exam in each course, the students were asked to complete a questionnaire. Two brief, interactive lectures were then given introducing metacognition, Bloom's taxonomy, and some strategies for studying and learning. Evidences were shown to the students proving the effectiveness of these strategies and the understanding of metacognition, in general. A few exercises encouraging students to teach one another were included in each course.

Students completed another non-anonymous questionnaire at the end of the course to determine how students had changed their study/learning behavior. Anonymous responses to questions in course evaluations were collected at the end of the semester, providing students an opportunity to express themselves anonymously.

Results in the form of exam scores, both collective and individual, are presented. Several students made notable improvements through the course of the semester, and those results are shown. Student responses to questionnaires, both anonymous and named, are summarized.

Overall, the students in the courses included in this study did not perform exceptionally compared to students in previous semesters who did not experience a formal intervention on metacognition. One exam grade appears to be better than previous semesters to a degree that more than "chance" was probably involved. A small number of students succeeded in bringing their grades from an initial failure (Exam I) to a satisfactory course grade. The fraction of students achieving this was greater in the fall of 2017 than historically.

Introduction

A perception exists that students' present high school experiences do not – or, perhaps, no longer – motivate them to learn to study and learn [2], [3]. This, at least in part, has prompted researchers such as McGuire [1], Tanner [4], and Taraban, et al. [5] to try to fill that void at the college freshman level.

McGuire [1], Emerita Professor of Chemistry, Louisiana State University, was early very active in introducing metacognition to her freshman chemistry students. Many students take chemistry the first semester of their college experience. If students have not yet learned how to learn, taking the opportunity at this level to intervene seems ideal.

In a discussion on college student retention, Kuh [3] wrote, "...if students do not do well in English and advanced mathematics classes ..., interventions later usually have only modest effects on their chances to complete a baccalaureate degree." Although studies were not cited to support this statement, it seems self-evident, earlier interventions should be more effective than later interventions.

Tanner [4] repeatedly refers to *introductory* undergraduate biology courses. She does not expressly limit her work to freshmen (or, in fact, to any other class). Notwithstanding, introductory biology being taken, frequently, by freshmen, it seems possible, the work focused on that level.

Taraban, et al. [5] focus, explicitly, on freshman academic performance.

One might argue a challenging curriculum at the high school (or even middle school) level would be a preferred solution to this problem. However, when students matriculate into an institution of higher learning having never been challenged, the issue must be addressed later than might be preferable – if it is to be addressed at all. Further, if no program to mitigate students' lack of understanding of learning practices exists – or students are not involved in a program – at the college freshman level, the solution, if any, must be effected after the freshman year.

In a largely student-structured, project based learning environment, junior and senior engineering students were included in a study [6] to enhance lifelong learning via metacognition. Cunningham et al. [7] included sophomores in the first phase of their study. Their approach was to provide students with short videos and assignments to provide background and framework for metacognition.

Clearly, non-freshmen undergraduates have been included in some studies on metacognition. However, there is an apparent need for better understanding of the possibilities for enhancing student performance by presenting metacognition at a more advanced stage of the students' college career.

Background

For the instant investigation, the hypothesis is: it is never too late for students to learn how to study and learn. Students involved in the study were taking the first semester thermodynamics

course or the fluid mechanics course taken by those majoring in mechanical engineering. Metacognition is not a usual part of the curriculum at Trine University. Although no formal attempt was made to determine if any of the students had encountered teaching on metacognition, none indicated so at any time during the semester.

Thermodynamics is populated, mostly, by second semester sophomores. Spring semester 2017, the class comprised 22 students, 20 of whom permitted the use of their data for this study. Of those students, seven were biomedical engineering students and fifteen were mechanical engineering students. The makeup included nine female and eleven male students.

Students taking Fluid Mechanics are mostly first semester juniors, all majoring in mechanical engineering. Two sections of Fluid Mechanics comprised 43 students who finished the course. Of those, 42 granted permission to use their data for this study. The Fluid Mechanics class included two female students.

Both courses were inverted or flipped. Students viewed lecture videos on their own time. Class time was devoted to quizzes, class examples, and working practice problems. The inverted mode of instruction made the introduction to metacognition easy to work into the classes.

Students in both courses worked in groups of two (rarely three when an odd number of students were in the class). Quizzes over practice problems were worked as a group effort. Exams were completed individually.

Lectures

McGuire [1] suggests introducing metacognition after the first exam or a major quiz. This is so students have a fresh experience from which to realize their need for better understanding.

Based on McGuire's [1] recommendation, after the first exam in each course, two brief, interactive lectures were given during class time. Bloom's taxonomy was explained and students were asked to comment on the level within Bloom's required to succeed in high school and, again, in college. Emphasized topics included learning rather than memorizing, learning sufficiently well to teach subjects, the importance of reading the text, and each student assessing his/her level of learning.

Specific strategies to enhance learning introduced in these lectures included working problems without referring to an example, the intense study cycle [1], teaching the material to others, chapter and concept mapping, and flashcards.

Working a problem while looking directly at a worked example of a similar problem is common practice. The students involved in this study were encouraged to study examples before attempting the practice problems without an example at hand.

The intense study cycle is detailed in [1]. It provides an organized approach to uninterrupted study with a predetermined duration.

As we involved in pedagogy well know, learning material sufficiently well to teach it is to learn that material well. McGuire [1] suggests “teaching” can be done productively to an empty chair or a stuffed animal. The students were encouraged to teach each other and, if that were unviable, to teach a chair, mirror, stuffed animal, young nephew, etc.

Chapter and concept mapping are methods to help organize one’s thoughts and understanding of different topics. They help to categorize topics and ideas. A chapter map may be completed using only the index of the text for a class. It involves writing down the chapter title and the titles of all the headings, subheadings, etc. For concept mapping, a student writes two concepts having similarities and differences, then lists those similarities and differences. For instance, the equations for the first law of thermodynamics for closed systems and for open systems may be contrasted.

Flashcards are self-explanatory. Although some students do not believe they are helpful in the courses included in this study, other students found them helpful. They have the advantage of being flexible and handy. They can be made to nearly any size, so they can be carried in a pocket or bookbag. A student can run through a set of flashcards while waiting in line for lunch or between classes.

Exercises

One of the most emphasized tools for improving learning was teaching. McGuire [1] suggests students can benefit by teaching an empty chair or stuffed animals. Of course, students may also teach other students. Two intentional opportunities for the latter were provided in each of the courses. Because the students worked in groups, having one of the partners teach the other was obvious. Discussion afterward about this teaching experience and results emphasized the importance of using this technique for learning.

The last week before final exam week, Thermodynamics students were provided with forms for constructing contrast maps. The forms were filled out in class in collaboration with group members. Discussion followed to make sure the results were complete. Comparisons were made between similar equations for closed and open systems, and between similar equations used when specific heats are variable and when they are assumed constant.

Assessment Tools

Questionnaire 1

After the first of these two lectures, the students were asked to fill out a questionnaire based on Dawood's unpublished work (presented in [1]). Questionnaire 1 is reproduced in **Figure 1**.

Reasons I did poorly on Exam I:	Rating:
1. Spent insufficient time on the material.	_____
2. Did not keep up with the Practice Problems.	_____
3. Did not start with the equations on the Equation Sheet while working Practice Problems.	_____
4. Did not read the text before viewing the lecture videos.	_____
5. Did not view all the lecture videos before class.	_____
6. Believed I understood the material before the exam.	_____
Total:	_____
Reasons I did well on Exam I:	
1. Skimmed or read the book before viewing lecture videos.	_____
2. Reviewed the lecture notes after viewing the lecture videos.	_____
3. Kept up with working the Practice Problems according to the syllabus.	_____
4. Worked Practice Problems for <i>understanding</i> , not just to complete them.	_____
5. Taught concepts to others.	_____
6. Asked Dr. Batson (in class or in his office) or a tutor for help when needed.	_____
Total:	_____

Figure 1. Questionnaire 1 completed by students after the first lecture on metacognition.

Questionnaire 1 may also be considered an *exam wrapper* [8]. A commonly stated objective of exam wrappers is that of personal reflection among the students, and most authors focus on this purpose. The Center for Engaged Instruction at UC Irvine [9] also suggests, “Apart from fostering metacognition, wrappers provide professors with data on the study habits of top-performing students, data that can then be shared with the rest of the class.” The main purpose of Questionnaire 1 was similar to this suggestion in [9], but was intended to display the results of learning and study habits of *both* high- and low-performing students. Before the questionnaire was distributed, it was hoped each section’s summarized responses would clearly (even strikingly) exhibit the effects of learning/study behaviors, both productive and unproductive, on exam scores. As can be observed in **Figures 2a** and **2b**, that hope was realized for each class.

All students filled out both parts of the questionnaire. It was not anonymous. They were to rank the statements 0–4 based on:

- 0 — Completely disagree
- 1 — Partly disagree
- 2 — Neither agree nor disagree
- 3 — Partly agree
- 4 — Fully agree

Each of the two parts of Questionnaire 1 (“did poorly,” and “did well”) were totaled separately by the students as shown on the questionnaire. An individual was placed in one of two categories based only on which total was greater for that student. Average exam scores for each category were calculated and the results were presented to the students in the second lecture.

The average exam scores of the respective class in each of the two categories were depicted as bars in bar charts as seen in **Figures 2a** and **2b**.

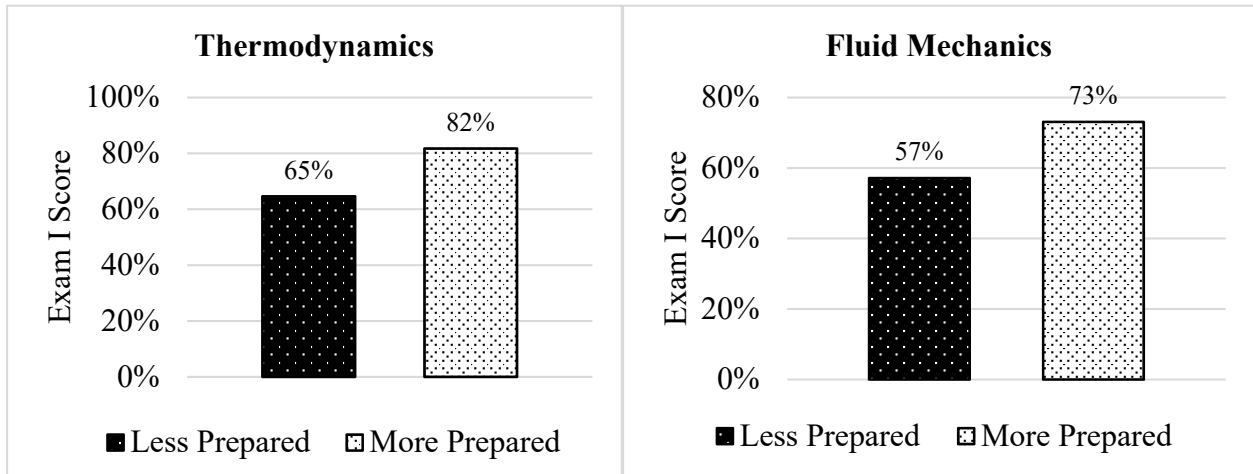


Figure 2. Questionnaire results. (a) Thermodynamics (b) Fluid Mechanics.

As **Figures 2a** and **2b** were presented to the student, emphasis was placed on the fact that these two categories, “Less Prepared” and “More Prepared,” were based entirely on study practices and behavior. In particular, the differences in scores were not due to any direct measure of intelligence.

Commitment

Although not intended as an assessment tool, after the two lectures on metacognition, students in both classes were asked to commit to using at least one of the learning techniques discussed. They could choose more than one, and many did so. No attempt was made to assure students actually made use of any of these methods, whether committed to or not.

Following are the techniques committed to by students.

Thermodynamics

- | | |
|--|-------|
| 1. Preview-read-review | 42.9% |
| 2. Use the intense study cycle for Practice Problems | 71.4% |
| 3. Chapter or concept mapping | 19.0% |
| 4. Practice teaching the material | 61.9% |
| 5. Flashcards | 9.5% |
| 6. Other | 9.5% |

The two students who marked “Other” described their plans as:

- Reviewing notes more often.
- Working problems from other sources, such as the *Thermodynamics Problem Solver* by REA.

Fluid Mechanics

- | | |
|--|-------|
| 1. Preview-read-review | 59.5% |
| 2. Use the intense study cycle for Practice Problems | 69.0% |
| 3. Chapter or concept mapping | 7.1% |

4. Practice teaching the material	69.0%
5. Flashcards	26.2%
6. Other	2.4%

The two students who marked “Other” explained, “Get help from Dr. Batson.”

Questionnaire 2

During the week before final exams, the classes filled out a second questionnaire. In that questionnaire, students were asked to rank their study practices on a scale of 0–3 with:

- 0 — Virtually never
- 1 — Sometimes
- 2 — Usually
- 3 — Nearly always

The study practices in the questionnaire were those presented in the lectures on metacognition, and some of those committed to by students at the end of those lectures. The questions were:

1. I *skimmed* the associated text material before viewing the lecture videos.
2. I *read* the associated text material before viewing the lecture videos.
3. I viewed the lectures before the class period for which they were listed on the syllabus.
4. I reviewed my notes for a given lecture by shortly after the class period for which it was listed on the syllabus (at the latest).
5. I used the study cycle with intense study sessions.
6. I worked Practice Problems without looking at an example (at least for the first fifteen minutes).
7. I worked Practice Problems with a study group.
8. I used concept (chapter) mapping.

The average of those rankings is shown in **Table 1**.

Table 1. Results from Questionnaire 2.

Thermodynamics				Fluid Mechanics			
Question	Average	Question	Average	Question	Average	Question	Average
1	0.70	5	1.50	1	0.66	5	1.57
2	0.40	6	2.05	2	0.41	6	1.82
3	2.80	7	0.95	3	2.80	7	1.54
4	1.85	8	0.40	4	1.71	8	0.59

Although 42.9% of Thermodynamics students and 59.5% of Fluid Mechanics students committed to reading their text (preview-read-review), nearly no student actually carried that out in practice. Only one Thermodynamics student (5%) and one Fluid Mechanics student (2.4%) selected “Nearly always” for question 2. Two students (4.8%) in fluid mechanics selected “Usually.” No Thermodynamics students “Usually” read their text. Five (25%) Thermodynamics students chose “Sometimes.” Ten (23.8%) Fluid Mechanics students selected “Sometimes”. The remainder, 60% of Thermodynamics students and 69% of Fluid Mechanics students, went on record as “Virtually never” reading their text.

Students in both classes were regularly and formally quizzed about their video lecture watching, which explains the high averages for question 3.

Reviewing notes and efficacious practices in working problems were more popular than reading the text.

Concept and chapter mapping were not popular study techniques, but one Fluid Dynamics student selected “Nearly always” for that technique. One Thermodynamics student and five Fluid Mechanics students chose “Usually.” Six Thermodynamic students and eleven Fluid Mechanics students believed they “Sometimes” used concept or chapter mapping.

No correlation between any of these practices and final course grades is evident. One possible reason for this is some students already have an understanding of metacognition, and a system that works for them.

Top performing students in both classes had a common refrain. The student earning the second highest score in Thermodynamics wrote on Questionnaire 2, “I have an atypical learning style. I thought the info was helpful, but my learning style does not correspond with those methods.” Whether or not this student has an “atypical learning style,” this comment emphasizes the meaning of metacognition. The top scoring student in Thermodynamics simply wrote, “I did not use the lessons learned about metacognition.” In the Fluid Mechanics class, the second-ranking student wrote, “...I did not utilize the information presented about metacognition because I already have a system of studying and learning that works well for me.” Perhaps these last two students’ understanding of the meaning of metacognition was too limited. A valid argument is that they *did* effectively use metacognition, just not the specific study method presented. All students should develop a system of learning that works for them – and that system does not have to include the techniques presented in the lectures.

Exam Scores

In each of the two courses, three exams were administered during the semester followed by a cumulative final exam. For comparison with the present Thermodynamics scores, 156 prior student scores were used to compute exam averages. Historical values were taken from semesters beginning with spring 2014. Fluid Mechanics student performance was compared to 146 students’ exam scores from semesters beginning fall 2014. The beginnings of the historical data were the initial semesters for inverted classrooms in each course.

In **Figures 3a** and **3b**, the average exam scores for the students included in the instant study are plotted next to historical averages. Clearly, success was not uniform. Error bars represent plus/minus one standard deviation.

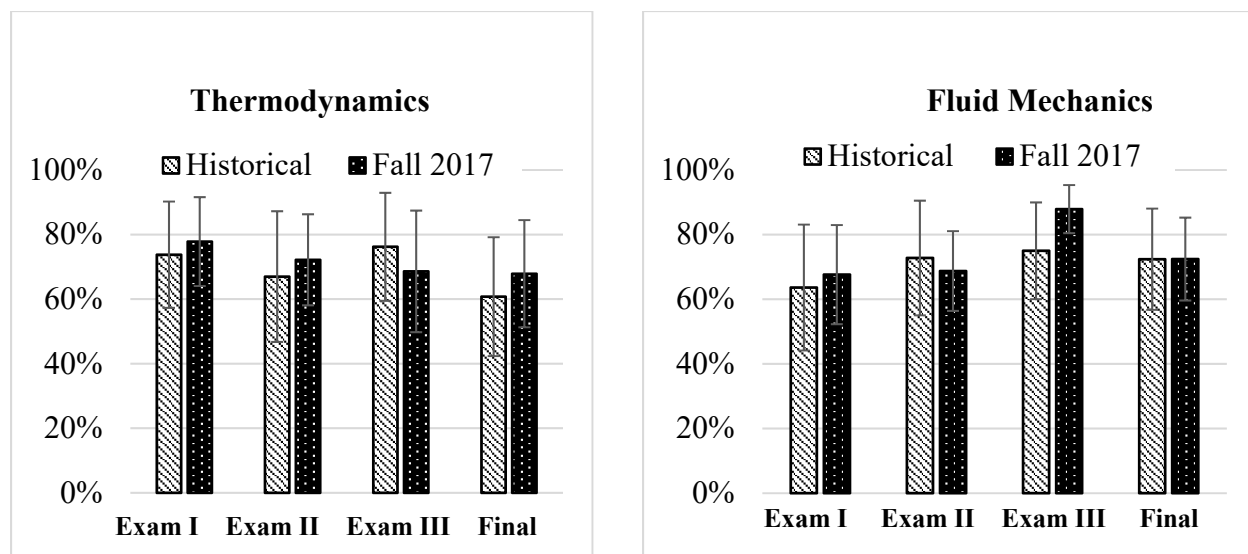


Figure 3. Exam score averages. (a) Thermodynamics (b) Fluid Mechanics.

To determine if there were significant differences between the scores from fall 2017 and historically, a two-sided t -test was performed on the students' test scores for each of the four exams given and for both courses.

For the exam scores in Thermodynamics, the calculated values of t for each exam was less than the tabulated t -value. So, the null hypothesis may be accepted, the conclusion drawn that there is no significant difference between the mean values of the test scores for the fall 2017 group and the entire historical group.

Turning to the Fluid Mechanics students' exam scores, the two-sided t -test showed no significant differences between Exams I, II, and the Final Exam of the fall 2017 class and the historical data. For Exam III, however, the calculated value of t is greater than the tabulated value. The alternative hypothesis must be accepted in this case. Clearly, the fall 2017 Fluid Mechanics exam scores were an improvement over the historical values. The same test questions used on an exam in a previous semester resulted in an average score of 85.1%. That score was achieved by a historically extraordinary class. Fall 2017, the average was 87.9%. The historical average is 76.3%. Of course, the result of the student t -test does not indicate the reason(s) the alternative hypothesis must be accepted. It must be admitted, there could have been other factors involved than the present study reveals.

Individual Successes

McGuire [1] reported several individual success stories. These stories highlight students who had not learned how to study and learn until metacognition was introduced to them. Then, when these students understood how to succeed, they did so, sometimes spectacularly. Similar stories were searched for in the present study.

Criteria for defining success is subjective. For this section, a "success story" was defined as a student earning a failing score on the first exam (before the lectures on metacognition) but earning a satisfactory (C or better) course grade. Historical data were searched for the same pattern.

Thermodynamics

Only one student failed the first Thermodynamics exam, fall 2017. That student did not earn a satisfactory course grade, so there were zero students in Thermodynamics meeting the criteria for a success story. Although it cannot be attributed to the lessons on metacognition (presented *after* the first exam), the fact that only one student failed the first exam is considered a positive for the class.

Historically, in Thermodynamics, three students met the criteria for a success story. There were 156 students in the historical group, making for 1.9% of the students having “success stories” without the benefit of metacognition lectures.

Because there were 20 students included in the Thermodynamics class for this study, a single student accounts for five percent of the group. Historically, only 1.9% of the students met the criteria for “success stories,” which is less than one student in the fall 2017 class. Even if the presentation of metacognition doubled the fraction of students meeting the “success stories” criteria, the expectation for fall 2018 would still be fewer than one student. Therefore, it is not surprising no fall 2017 Thermodynamics student’s performance could be considered a “success story” as defined, above.

Within the fall 2017 Thermodynamics group, an outlier is identified herein as *Student T*. Student T took Thermodynamics for the third semester in a row, fall 2017. The first two semesters, Student T dropped the course after the second exam.

The first week of class in the fall of 2017, the author asked Student T to his office. Because Student T had already experienced disappointment in Thermodynamics, it was assumed the time was right to discuss better learning habits. Therefore, the first week of class, Student T was exposed to the same metacognition information the rest of the class learned about after the first exam.

Student T chose to make use of the information and techniques presented in Thermodynamics and other courses, as revealed in private conversations. Despite the fact Student T’s first exam score was in the D+ range, and rather because of the remarkable improvement, Student T became excited about this success. Student T reported repeatedly that the lessons on metacognition and study techniques were the reasons for this accomplishment.

Exam scores for all three semesters for Student T are plotted in **Figure 4**. The class average for fall 2017 is plotted for comparison.

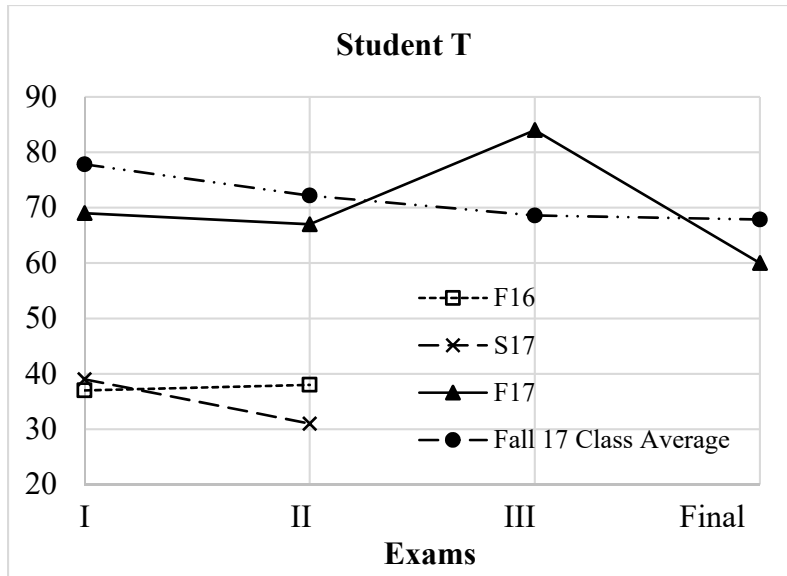


Figure 4. Exam scores for Student T.

Despite most of Student T’s fall 2017 exam scores being below the class average, Student T’s improvement from prior semesters is unquestionable. Scores for the first two fall 2017 exams were nearly the sum of the two prior semesters’ values. Student T earned a satisfactory course grade, and is a strong proponent for the learning and use of metacognitive strategies for academic success.

Five Fluid Mechanics students’ scores met the criteria for “success stories.” Exam scores are plotted in **Figure 5** along with the class average for each exam.

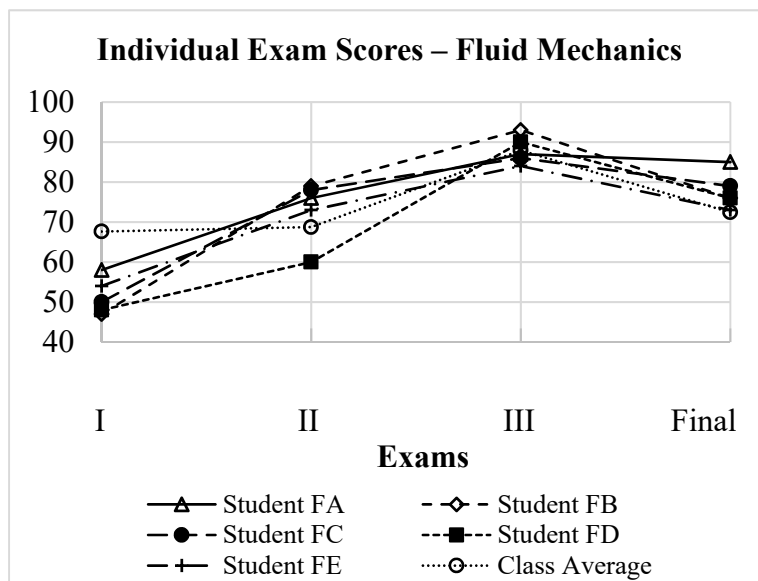


Figure 5. Exam scores associated with “success stories.”

These five students represent 11.9% of the fall 2017 Fluid Mechanics class. Historical data revealed eight students whose scores met the criteria for success stories. These eight students composed 5.5% of the historical group.

Observations and Further Work

Students were asked in non-anonymous questionnaires, anonymous evaluations, and private conversation how the process of conveying metacognition could be improved. Commonly, students felt the information should be presented earlier so it could be used on the first exam. Possibly, because the students in this study have several college semesters behind them (and probably some disappointments), they would be open to suggestions for improvement earlier in the semester. It may be, Fluid Mechanics students would be more likely to be receptive to methods of learning, having experienced the “difficult” Thermodynamics course. It might be useful to construct a study through which a comparison may be made between introducing the subject early – within the first couple weeks of class – and after the first exam.

Another common refrain among students was more frequent reminders, and possibly some more exercises. An improvement probably could be made by having students fill out more contrast maps, teach each other assigned subjects, map chapters, etc. The exercises, themselves, would be instructive, but also would remind students about metacognition and learning for understanding.

Several students were verbally enthusiastic about the possibilities with regard to metacognition. Some searched online to learn other techniques to apply. These students felt the topic was very valuable, and believed they achieved a better understanding of the subject matter, and higher scores.

Conclusions

The instant study clearly did not raise exam scores *en masse*. There were, however notable success stories among the students involved. By applying the possible improvements, above, and other changes that might suggest themselves in the future, perhaps more students may be reached. In any case, if one student realizes better understanding and a better grade, the effort has been successful. There seems to be no downside.

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