INTRODUCING REFLECTIVE LEARNING IN A LARGE PROBABILITY CLASS

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Reflective learning though popular in Humanities and Social Sciences is not widely used in STEM disciplines. We describe the introduction of weekly student reflections in a large Introductory Probability course and key takeaways from student and instructor perspectives. Reflections proved to be helpful to students in several ways - they made a challenging course more enjoyable, helped students articulate the concepts that they struggled with, think deeper about course materials and applications as well as take charge of their learning by organizing their study so as not to fall behind, make changes to their study habits, and seek timely help. On the instructor's side, student reflections were a tool to spark conversations and create a shared sense of learning and community while including and addressing diverse perspectives in response to questions brought up in reflections. Additionally, reflections gave the instructor a glimpse into all students' difficulties with concepts rather than just those who ask questions or attend office hours and helped enhance inclusivity by connecting personally with a large number of students in response to difficulties expressed with the course content.

INTRODUCTION

As the world pivoted to remote learning in 2020, many educators, including the first author as the instructor of a large calculus-based probability course wrestled with the idea of keeping students on track with the course content and mastery as students simultaneously were adjusting to remote learning. In response, weekly reflections were implemented as a tool to help students keep on track by reflecting on topics, ideas learnt each week as well as study habits; identifying challenging concepts; tracking activities they undertook (or missed), and resources they utilized during that particular week. Reflective practices, common across various disciplines such as Humanities and Social Sciences (Ross,1994), teacher education (Belvis et al., 2013; Russell, 2018), and writing (Yancey, 1998) have shown to be important in helping students make sense of and grow from a learning experience while also improving critical thinking skills and motivation in a challenging course. This research backed benefits of reflective practice in other disciplines were also observed in the statistics and data science course studied in this paper. In this article, the authors provide the relevant information about the course, explain how reflections were implemented, and describe the major findings from both an instructor and student perspective.

The research questions that guided this research were:

1. Do weekly reflections help students better understand course topics in a challenging introductory probability course? If so, to what extent?
2. Do students alter their study habits as a result of weekly reflections? If so, in what ways do they do that?
3. Do weekly reflections help develop stronger communication between students and instructors in a large enrollment course?

METHODS

Weekly reflection structure

The weekly reflections were introduced in the course syllabus and explained in the introductory lecture video explaining the course mechanics and assignments. Students were reminded about important deadlines for assignments, including the weekly reflection assignment, each week via a weekly email from the instructor. The weekly reflections were reviewed by the instructor each week to identify themes that emerged and topics that students found challenging. Having this insight into all student responses allowed the instructor to discuss major themes and to answer any students' questions through the weekly email from an instructor. Occasionally the questions that were brought up would require a more lengthy or elaborate explanation than the ones that were appropriate to include in the weekly instructor's email. The separate write ups were developed to answer deeper questions and were

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posted on the course website. Additionally, they served as supplementary reading material for future iterations of the course.

Course and Study participants information

Weekly reflections were implemented in a 4-credit hour, 300-student calculus-based introductory probability course, a first upper division course for Statistics and Data Science majors and a required course for several other STEM majors. Each topic builds on the previous topics making it very important for students to not fall behind and to seek additional help from course staff as early as possible. Weekly reflections were administered in all three quarters during the 2020 - 2021 pandemic academic year when the course was taught via fully remote instruction. Each week students viewed recorded lecture videos, participated in a discussion section via zoom conducted by a graduate teaching assistant (TA) and turned in a homework assignment. Assessments were conducted via a midterm exam (in Fall 2020), biweekly quizzes (in Winter 21 and Spring 21), and a final exam. Weekly reflections were graded for completion only with the lowest two out of ten scores dropped in the final grade calculation. Across the three quarters, on average 74% of the students completed between 8-10 (scored 100%) weekly reflections and 20% of the students completed between 4-7 (scored between 50-90%) weekly reflections. On average 210 reflections were reviewed each week and analyzed in this article.

Across the three quarters in which weekly reflections were implemented, on average the course comprised 28% statistics and data science majors, 14% computer science majors, 6% math majors, 7% actuarial science majors, 21% pre majors in mathematical sciences focus areas, and 24% other majors. In terms of the year of study, on average the course comprised 2% freshman, 23% sophomores, 57% juniors, and 18% seniors.

Sample weekly reflection questions

Given our research goals to understand how reflections helped students understand the course topics and alter study habits, we constructed weekly reflection questions by looking at the questions implemented in humanities and social sciences as well as in other STEM disciplines (Dounas-Frazer & Reinholz, 2015) and 6-12 grade math courses (Boaler, 2015). Some sample reflection questions are listed below.

Each week the reflection consisted of a combination of:

1. A standard set of questions regarding activities and resources students undertook. For example,
    - *What resources have you used this week? (List of resources provided),*
    - *How much of the homework due next week have you completed?*

   Such questions subtly remind students of various resources available or work left to do.
2. A set of questions that varied across the weeks depending on:
    a. the course content for the week. For example.
        - *Have you seen the picture mentioned in lecture videos in any commercial or logo before? Why do you think it was added there? (Be creative),*

    b. or questions designed to help students see connections between lecture, discussion, practice, and homework. For example,
        - *Write about one way that working on the practice problem set helped you with homework,*

    c. or questions geared towards thinking about application of probability concepts
        - *Have you found any applications of probability concepts that are relevant in your own life? If so, write a little bit about these applications.*
3. In weeks before major assessments, questions were designed to nudge students to start planning their preparation for approaching higher stakes assessments. For example,
    - *If you do not yet feel fully prepared, please describe some of the resources you're planning to use to study.*
4. Or a few open-ended questions to help ease the stress of remote learning. For example,
    - *Write a joke about probability or statistics that you have found to be amusing :) (It is okay for you to search the internet and cite the source)*
5. Or questions to build critical thinking skills. For example,

- *Find an article in the media that shows the relevance of probability in real world applications or everyday life. If you can't find an article, read the article provided and explain areas in the article where the concepts we've learned appear to be relevant.*

Data analysis

To analyze the student reflections, we used thematic reflexive analysis, which requires researchers' recursive engagement with the dataset. The following steps were taken throughout the data coding and analysis: familiarizing yourself with the dataset (reading the content and creating analytical memos); coding data (generating codes that are relevant to the research questions); generating initial themes (identifying broader patterns); developing and reviewing themes that correspond to the research questions; refining and naming themes while providing detailed analysis and interpretation; and writing up the results (contextualizing analysis with existing research) (Braun & Clarke, 2006). Although presented in a linear manner, the analytical process was iterative, fluid, and recursive in nature rather than rigid and structured (Braun & Clarke, 2019). Inductive approach was applied to the data coding, allowing the codes and themes to emerge from the data instead of relying on the preset list of codes. In reflexive thematic analysis, the researcher's subjectivity is understood as a resource as the researcher's immersion in data, thoughtfulness, and reflection can help inform data interpretation and analysis (Gough & Madill, 2012).

RESULTS

The following themes emerged from the student reflection data.

Theme 1: Reflections helped students develop deeper understanding of the course concepts by offering more opportunities at formative and self-assessments.

In a survey about reflections during the last week of the course, about 88% of students indicated that the reflections helped them think about applications and also to think deeper about course material; about 73% of students indicated that reflection surveys gave them a way to express their understanding of course topics and about 62% indicated that reflection surveys were a chance to think about concepts they did not fully understand that week.

A student comment in a reflection early in the quarter shows how reflections helped grasping and deep understanding of concepts: "*I never really totally grasped the union, intersection, and complement concepts. I know it's remedial, but I always kind of glossed over it. I really deeply understand it now (for how little there is) and I'm excited to move on."* The usefulness of reflections as an opportunity to review material weekly was expressed by another student as "*I think the reflection surveys are really useful for the review of the week's contents, so I hope it can be kept for future courses.".* One more student comment shows the usefulness of reflections in self-assessment to identify areas to focus on after completing the reflection assignment in an effort to improve course grade: *"If you want an A, then you should take the step forward to review your work and topics after the reflection survey."*

Theme 2: Reflections made students proactive in their learning, made them aware of managing time and making use of extra resources provided to help them succeed.

In the final week survey about reflections, about 80% of students indicated that reflections (i) helped make the course material more enjoyable, (ii) helped them organize course work for the upcoming weeks and not fall behind in the course and (iii) should be continued in the next course offering; and about 53% of them indicated that such weekly reflections of the course material is a tool that they learned and that they will probably use in other courses.

Reflections gave students an opportunity to review their understanding as well as study habits and reallocate time as appropriate each week as expressed by such student comments as "*I still need some more practice with Multivariate Distributions. Since I got a horrible grade on the last quiz, I tried to put in more hours for this class.", "Still need to put some more time into understanding correlation and covariance".* Additionally, reflections gave students an opportunity to take charge of their own learning and seek out support and resources in a timely manner as evidenced by the following student comments: "*I'm still confused about the central limit theorem. Gonna watch the lecture again."* and *"I*

am still confused with the central limit theorem conceptually, but I plan on attending office hours this week to get a more thorough explanation on its applicability and relevance." Reflections prior to exams show that students realized that practice is important in a math course and also planned to use the available resources, such as office hours and review sessions to help them be better prepared for major assessments as demonstrated by the student comments: "*I plan to redo all the practice problem sets and homework. If I still don't understand a concept, I will visit office hours. I also plan to go to the final exam review session on Tuesday." and "I plan to go and (re)do all the practice problems and try to do them without referencing notes. When I need to reference notes, I plan to write down the stuff I need to reference."* A few reflection questions were deliberately light hearted to ease things up in a challenging course and as intended seemed to make the material enjoyable as illustrated by a student comment *"I still remember the survey in week 1, in which I was asked to find a research essay. I think that is enjoyable."*

Theme 3: Reflections provided a way for the instructor to create community as well as provided a channel for two-way communication and feedback between students and instructor.

Achieving interaction in a live large lecture classroom is difficult enough and effective interaction with all students is extremely challenging in the remote environment.

In the initial weeks, students who missed completing the low-stakes reflection assignment were contacted via light touch feedback (Flaherty, 2019) by the instructor. This was a quick way for the instructor to connect personally and communicate care with students who may have forgotten to submit and thereby earn additional points towards their grade as is evident in the following student reflections *"I forgot to complete the reflection survey and quiz on time, because I'm still a little confused and trying to figure out things during the brand-new semester. I'll make sure I remember to complete them on time. Thanks again for the nice reminder."* Furthermore, weekly reflections provided a way for students to feel connected and part of the learning community as illustrated by a student comment *"The weekly emails, reflection surveys, and gentle reminders were extremely helpful this quarter in particular. I feel very detached from the school and my classes, and this frequent contact made me feel a little more part of the class and in control of my learning. Thank you."*

Reflections resulted in increased communication and feedback provided by the instructor to students. In a large class such feedback from instructor to students is very difficult to achieve on a weekly basis. Having an insight into weekly topics that most students found challenging allowed the instructor to address the student questions brought up in weekly reflections via the weekly instructor email to students. This email, which was intended to serve as a reminder of the key due dates for the week, ended up being a means of communicating with students and answering the challenging questions or topics that students brought up in the weekly reflections. This further created a sense of community and shared goals towards learning and understanding of the course concepts in a challenging introductory probability course. Despite having taught this course several times before (without weekly reflections), there were a few key and deep questions in traditionally difficult topics such as moment generating functions that students posed to the instructor for the first time as they reflected on the material for the week. The instructor believes that some of these questions were possible only because reflection assignments encouraged students to reflect (on what they learnt, what they found surprising, what they found challenging and what they yet could not wrap their mind around) and also provided a vehicle for students to jot down their reflections.

DISCUSSION

Weekly reflections of (almost) all students in a large 300-person class provided the instructor with rich and valuable insights into difficulties with course concepts. Normally, in a large class, to gauge students' understanding of the course content, an instructor must rely on questions posed by very few students during lecture, or office hours, or via clicker responses. It is impossible to get feedback from every student on a regular basis in a large class but weekly reflection provided an avenue to do so. It is important to note that the feedback that stems after a student has spent time going over the course material and then reflecting on it, conveys a different layer of information to the instructor as compared with the feedback received via clicker questions during lecture. Clicker questions give students an initial idea of whether or not students are able to grasp a concept/topic while reflection shows students the obstacles they need to overcome and help them articulate what they need help with to fully understand

the concept/topic. In a probability course, which is known to be non-intuitive and even in other STEM courses that rely heavily on mathematics and formulas that can make content a bit dry and intimidating, allowing students to articulate exactly what they need help with is important and becomes key to deeper learning (McTighe & Silver, 2020) and learning that sticks (Goodwin et al., 2020). It takes time and engagement with using the difficult concepts for students to form a deeper understanding of the concepts. Reflections seem to provide a way for students to engage with difficult concepts and form a deeper understanding.

Another key takeaway of introducing weekly reflections, came from the instructor's own reflection of information and feedback from student responses was an iterative improvement and adjustment of course materials and assessments for the next and future iterations of the course. These improvements took the form of:

1. Providing additional resources that were created as a result of answering students' questions.
2. Providing additional resources, such as videos, notes or dedicated review sessions for reviewing pre-requisite material (e.g., reviewing double integrals before using double integrals to solve probability problems involving jointly distributed random variables).
3. A structural change in assessments from the first course offering was to split the mid-term into four evenly spaced quizzes to reduce stress and allow for frequent practice with course topics.
4. Consolidation and streamlining of weekly reflection questions as well as additional questions for the future reflection surveys to gain more insights and feedback for course improvement.

One such question that was added in the second iteration of the course was *"How do you feel about material this week?"* with responses on a 5-point Likert scale ranging from "too easy" to "too challenging". Week 5 responses to this question were not collected since a mid-quarter survey was implemented instead of reflections. A stacked bar chart of responses is shown in Figure 1 and 2.

Figure 1 and 2: 100% Stacked bar chart of Weekly reported difficulty level of course topics.

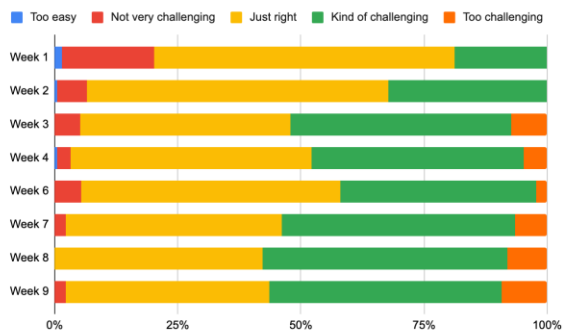

Figure 1: 100% stacked bar chart of reported difficulty level (5 levels) each week showing none reporting too easy (level 1) after Week 1 and very few reporting Not very challenging (level2) after Week 2 suggests taking a look at only levels 3 and higher as shown in Figure 2

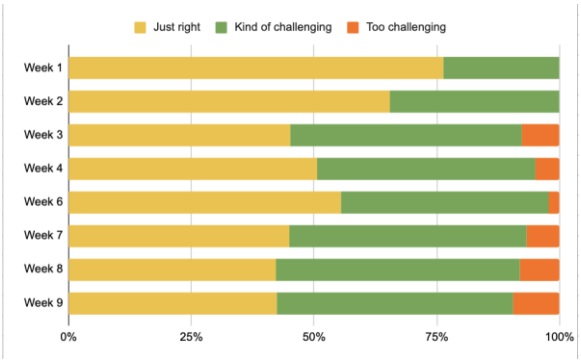

Figure 2: 100% stacked bar chart of reported difficulty level (levels 3, 4, 5 only) each week showing roughly 50-50 split for all weeks after Week 2 between just right (level 2) and kind of challenging (level 3).

Figure 1 shows that the course provided a good level of difficulty and rigor without being too easy or too challenging for the majority of students. The proportion of students that found the course "too easy" or "not very challenging" decreased rapidly.

Feedback from the first iteration of reflections suggested providing a refresher on double integrals (a prerequisite course material) right before Week 6 (where probability calculations involving using double integrals are introduced) would be helpful. Figure 1 further shows that this timely intervention made the same material easier in the second iteration as was also evidenced by an increase in scores on the final exam for questions related to double integrals. Figure 2 showing just three levels of responses, shows even more clearly that Week 3 (Introduction of Random Variables) and Week 7

(Introduction of bi-variate distributions) appear to be challenging topics while in Week 4-6 and Week 8-9 students seemed to get more comfortable with the same material. Theme 2 (that reflections made students more proactive in their learning) seems to explain this comfort level in Week 4-6 and Week 8-9 in that once a challenging topic emerged in Week 3 and Week 7, students' reflections helped them identify actions they needed to take and the various resources available to help them making the later content more comfortable. Figure 2 also shows room for improvement and interventions to increase the proportion of students who found the course just right in terms of difficulty which can take the form of providing more resources or building the Undergraduate Learning Assistant program specifically for the course.

CONCLUSION

Introducing reflections in a challenging probability course was beneficial in enabling students to self-regulate their learning and be proactive in adapting their study habits to utilize resources and seek support in a timely manner so as not to fall behind. In doing so, they also learned a tool to help them take charge of their learning in their future classes. For the instructor, reflections sparked conversations with students, allowed the instructor to connect personally with students thereby promoting inclusivity and addressing diverse perspectives despite the oddities and chaos of the pandemic teaching modality. It also helped identify course improvements based on feedback from *all* students' challenges with course concepts. Weekly reflections complement formative clicker assessments and help provide an avenue for deeper learning and learning that sticks. As demonstrated in this article reflections can be incorporated in STEM courses as well. Avenues of future work include generating a repository of general reflection questions that can be incorporated by any instructor in any course and course specific questions. Such a repository will help easier incorporation of reflections in STEM courses.

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