

Writing in a Mathematics Class? A Quick Report on Classroom Practices at the Collegiate Level

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Abstract

This teaching report describes a series of writing assignments for the college mathematics classroom that can easily be adapted to other disciplines. It focuses on examples of personal, expository, and expressive types of writing assignments and provides ideas for evaluating these assignments.

Keywords

writing, mathematics, assignments, evaluation, examples

Maria Fung first started using writing assignments in her calculus courses as a graduate student at Cornell University, and then taught for seven years at Western Oregon University (including several writing-intensive courses) before coming to Worcester State College. Her main interests lie in active pedagogical methods, mathematics education, and the mathematics preparation of K-12 teachers.

Introduction

With the revival of writing-intensive courses or writing across the curriculum (WAC) initiatives (Bazerman & Russell, 1995), each of the academic disciplines has had to re-examine, update, or create venues for fulfilling these demands. Mathematics at the collegiate level has been traditionally taught in the conventional lecture-discussion format, with regular homework problem sets and testing in the form of quizzes and exams. With the expansion of the WAC initiatives, however, mathematics instruction has had to expand its repertoire to include a variety of writing assignments throughout the curriculum, with the goal of improving mathematics achievement and retention of students. This short report considers specific examples of writing assignments, from the simple to the more complex. It also shares sample rubrics for evaluating these assignments.

Significant issues in mathematics education at the college level include underachievement and lack of motivation in students; persistent difficulties with abstraction, symbolic representation, and proof; and the resulting inability to apply and connect ideas across different contexts (Krantz, 1999). Finally, there has been severe anxiety reported among certain groups of students which negatively affects their ability to learn and retain mathematics knowledge (Perry, 2004). Recent educational research supports the view that learner-centered instruction that involves students' actively thinking about, discussing, and reflecting on their learning helps mitigate all of these problems. The individual and the social aspects of learning can be combined successfully in classrooms that use a variety of active learning strategies and cooperative groups. In

particular, classrooms where students both discuss and write about the mathematics they are studying show significant gains over traditional classrooms, even ones where one of the discourse or writing techniques was applied (Cross, 2009). Hence it might be beneficial to college instructors in mathematics and other disciplines to consider adding writing activities to their pedagogical tools.

Writing requires sustained thinking and reflection. It is shown to promote understanding and positive attitudes in mathematics, and it helps students in constructing new mathematics knowledge (Russek, 1998; Abdalkhani & Menon, 1998). Well-designed writing assignments can provide students with opportunities to practice mathematical inference, to communicate mathematical ideas, to organize their thinking, to interpret results and solutions to problems, and to make connections between different concepts (Abel & Abel, 1988; Countryman, 1992; Meier & Rishel, 1998). Thus writing can be a pedagogical strategy that moves students through the levels of Bloom's taxonomy (Bloom, 1956), away from simple recall of mathematical facts to understanding the concepts and applying them in different contexts in the process of problem solving. Furthermore, students can be asked to write down their conjectures through experimentation and generalization, as a way to synthesize new knowledge. Finally, students can use writing to analyze and to evaluate their own or their peers' work on a mathematical problem. Writing can be an invaluable tool in getting students involved in the learning process and in discussions with both their peers and the instructor in the course; it can complement the writing development of college students by providing a different opportunity to generate ideas in writing that are discipline specific (Pugalee, 2001). Moreover, writing in mathematics can help both teachers and students figure out and address misconceptions (Evans, 1984).

Types of Mathematical Writing

The writing process in mathematics can be divided into three categories: personal, expository, and expressive (Meier & Rishel, 1998). Examples of personal writing include letters, personal reflections on a specific topic, and journals. Expository writing ideas include short paragraphs or entire essays on specific topics in mathematics, research papers (e.g., in an elementary statistics course or as a senior project article), or simply recording or revising the answers to a test. Expressive writing examples include problem and story writing and other creative pieces. For each of these three types of writing, assignments can be designed at beginning or advanced levels.

Personal Writing Ideas

Personal writing is by its very nature informal. Among all three types of writing in the mathematics classroom, however, personal writing can best provide immediate and invaluable information to a college instructor about the history and/or present state of affect and grasp of the material for each student. This in turn allows a professor to make thoughtful instructional moves grounded in the acquired information about both her students' affect and the state of their learning that these assignments provide: Which topics should an instructor focus on when reviewing for a test? Is there a need for an extra problem solving set or another in-class activity that can clarify concepts and address misconceptions? The answers to these questions can be readily obtained from personal writing assignments.

From the learner's perspective, a personal writing exercise could be seen as an opportunity to have her voice heard and her anxieties, successes, or difficulties shared and addressed privately. Most students who are too shy to speak up in front of an entire class (whether to ask a question, contribute to a whole class discussion, or point out a mistake) will be able to articulate their

issues with the material in a course when prompted to write about it. This type of writing can make a learner more keenly aware of her strengths and weaknesses, and thus ultimately help her make better study decisions.

A college instructor can easily incorporate a variety of writing ideas from this category, from simple to more complex ones, without having to restructure her entire instructional practice. An added bonus for this category of writing assignments is the lack of time-consuming assessment—typically most of these assignments are simply perused and checked off. Here are some examples of personal assignments, arranged in order from the simple to the more complex:

1. After distributing index cards, a professor could ask her students to discuss which was the most difficult problem or idea from the homework, lab experiment, or assigned reading. This assignment can be done either at the beginning or at the end of the class period, and they can be anonymous.
2. Instructors can use exit cards (also known as *Do-It-Nows* or *Ticket-to-Leave*) with simple prompts like these:
 - One idea from today's lesson I find compelling is....
 - One idea I am still struggling with is....
 - For me calculators are....
 - To study for a mathematics test I....
 - I can do word problems when...
 - Factoring is easy when...

These prompts can easily be modified to fit different disciplines. These writing exercises are quick to administer, and they provide valuable immediate feedback about students' understanding, habits, and struggles.

3. Instructors can use free writing in their classrooms as a way to introduce a topic or focus the attention of the entire class on a specific concept. Students are typically given a short

fixed period of time (five minutes or less) and asked to describe everything that comes to mind when thinking about a specific idea. For instance, pre-service elementary teachers could be asked to describe everything they remember about fractions from their school days, or calculus students can be asked to describe what calculus means to them at the end of a term. An instructor needs to read these written responses right away as a way to modify lesson plans based on the input and background of the students. In a classroom where students feel safe to share their false starts and misconceptions, these free writing assignments can be read by, reviewed, and discussed with peers in small groups. The exchange of ideas usually results in improved learning of the topic, since it involves different perspectives and approaches.

4. Mathematical autobiographies are a perfect first homework assignment in almost any mathematics course. They can be topic-specific (for instance, a algebra or geometry autobiography) or more general. Students should be encouraged to share not only what they learned in their previous mathematics classes, but also the accompanying feelings any particular mathematics subject evoked in them throughout their schooling, together with information about how their overall attitudes evolved over time. The data from these essays is invaluable for an instructor's quest to get to know her students at more than a superficial level and to foresee ways to resolve any problems that might arise due to previous traumatic experiences or anxiety. Autobiographies also help students see themselves at the center of the learning process.
5. Journal entries can take on several forms depending on the mathematics course and its

goals. Journals can be completed for every class meeting, or on a weekly or bi-weekly basis, and they can focus on a specific topic (e.g. one idea per writing period) or a more general response. It is important to give complete and precise instructions to the students regarding content. For example, a journal might include false starts in problem solving, feelings about mathematics, and attitudes towards the material in the course. Journals are meant to be interactive, and thus need to be returned promptly to students. With the advent of modern online systems, journal writing can be relegated to online discussion forums or sent electronically to instructors in almost real time. Even though they are time consuming for professors, journals have been widely used in practice and have been the most researched type of personal writing assignment in mathematics education for over two decades: they have been found to improve mathematics knowledge and its retention (Keith & Keith, 1985).

6. Letter writing can be used in variety of contexts in the mathematics classroom. Most typically, it will involve writing a letter to a peer who missed a class and needs to have a complete explanation of the important ideas and concepts studied in his absence. Sometimes students can also be asked to write a letter to a novice in the field (e.g., a mom with no formal mathematics training is interested in knowing about an interesting mathematics fact like the fact that the difference of two successive squares of the positive integers is always an odd number). Pre-service teachers can be asked to write a letter to a child in their future classroom who is struggling with a particular concept (e.g., a middle schooler cannot understand the difference between median and mean for

a data set). Letter writing demands a different level of explanation from students—they need to put formal mathematical relationships into layman's terms and provide accessible examples of the relationships under question. They need to provide solid yet accessible justifications of their mathematical claims, moreover, and this process of looking at the same topic through a different lens makes them clarify and solidify their own understanding.

Personal writing ideas can be a regular part of the pedagogical toolbox of every college instructor. These writing assignments require minimal time investment for huge returns in terms of the immediate assessment that can allow a professor to tailor her instruction to the needs of her students.

Expository Writing Ideas

Expository writing assignments can vary from informal genres (and thus remain very similar to personal writing exercises) to formal projects that adhere to the highest writing standards of each discipline (e.g. research papers or senior theses). The main purpose of these assignments is to provide students with reflective opportunities to apply, analyze, and connect ideas from the content material. In mathematics learning, the knowledge of how to realize such applications, analysis, and connections is crucial to students' understanding and retention of material. Formal expository assignments, in addition to these properties, also contain the element of new knowledge synthesis and evaluation, which is the highest level type according to Bloom's taxonomy (Bloom, 1956).

From a learner's perspective, an expository writing assignment can be an opportunity for both reviewing mathematical topics and for learning new ones by deliberate focus on reflection, applications, and connecting ideas. There could be some resistance to writing in upper -level mathematics courses, since

some mathematics (and science) majors are anxious about writing. An instructor can alleviate some of this apprehension by providing very specific instructions for each assignment, by designing appropriate rubrics for evaluating such assignments, and by emphasizing the fact that high quality written communication is a significant learning outcome for each mathematics (and science) student. To be fully effective, expository writing assignments perhaps should be included as a part of the grading system for the course as a motivation for students' putting forth their best efforts in working on these assignments.

A beginner's expository writing assignment can consist of simple extensions to regular homework assignments and exams. These extensions put increased ownership of knowledge on the learner. For instance, at the end of a homework assignment, students might be asked to write a couple of sentences about which questions were difficult or easy, which applied a certain concept, and which caused them to get stuck. It is straight-forward to imagine how a traditional homework question can be transformed so it focuses on reflection: one can demand students to either present another strategy for solving it or discuss what mathematical knowledge assumptions are necessary for completing the problem.

On a test, questions that demand clear and precise explanations, illustrations, and descriptions are bound to produce effective writing in the discipline. For example, on a college algebra test, students who have studied the properties of quadratic functions can be asked to describe all possible graphs of quadratic polynomials and to relate these graphs to specific properties of the polynomials, such as their x - and y -intercepts. This exercise helps students revisit all the information they have learned about quadratics and try to produce a generalization about the relationship between graphs and intercepts, again moving them up through Bloom's knowledge levels.

Often students struggle with test anxiety, and one writing technique that might help relieve this anxiety is to offer students the opportunity to submit test corrections for credit, a process known in education as remediation. These small writing assignments involve a description of the initial mistake, a corrected result, and a short explanation about what caused the error. Test corrections can be utilized with great success in any lower-level mathematics course where student achievement and anxiety pose a real challenge—remediation forces students to revisit their exams and learn material they were not comfortable with at the time of the exam.

Open-ended or more complex mathematics problems and outside-of-class projects can also be used as expository writing assignments, especially if they are to include a deliberate reflection element. For instance, students in any mathematics course can be asked to solve a "problem of the week" or "mastery problem" that require a looking-back component incorporating verification of results, or false starts, or connections with other mathematical problems and ideas. Small cooperative groups can work on a series of problems related to a central topic in the curriculum (usually known as projects) and write a project report of their findings, together with a log of meetings and what was accomplished at each step. In upper-level courses, these projects are written using the formal language of the discipline and generally account for a significant proportion of the overall assessment of each student. Small changes in traditional outside-of-class homework assignments and projects that add an important reflection element have the potential to increase student learning value by requiring a much higher level of metacognitive awareness.

In lower-level mathematics (or science) courses, students can be asked to write formal reports on a specific topic that lies outside of the material covered in class or about a specific application of the material; this choice typically will not require any new mathematics

techniques. For instance, students in elementary statistics or college algebra can work on finding examples in the press of the uses of statistical displays and mathematical functions, respectively. They are instructed to make a display of these examples and to write a short explanation of what they observed and how it fitted with the mathematical definitions of these objects.

In higher-level mathematics courses, students can be required to recast a proof that has been worked out informally or intuitively in class as though they are submitting it to a formal mathematical journal. Sometimes an instructor might present a common student misconception to the entire class and ask the class to construct a response to the fictitious student who has made the mistake, with special emphasis on using correct terminology and proof techniques. This type of expository assignment is especially important for pre-service teachers who need to get used to analyzing students' work. It sets the stage for a robust class discussion of common misconceptions.

In mathematics classrooms where cooperative learning is a daily occurrence and student discourse is at the heart of most learning, students can be tasked with working on producing written posters, comparison charts, or other documents focused on a series of related topics from the curriculum. Each of the small cooperative groups is assigned a specific topic, and they are responsible for becoming experts on this topic by writing down all the ideas they can generate around this topic. Then group members move around the classroom to form new groups and share their knowledge. At the end of this group exercise (sometimes referred to as *jigsaw*), the entire class produces an extensive product. For example, students can work on comparing triangles in Euclidean, hyperbolic, spherical, and Taxicab geometries. A follow-up of this type of group writing assignment could be an individual essay written by each student about what was learned from this experience.

Another version of an expository group writing exercise is called *carousel brainstorming*. Group members are given different colored pens and tasked to record exactly one idea about a topic per round. (Groups can be given only one or several different ideas to consider in each round.) When the instructor gives a sign, papers are exchanged with group members, and new ideas are generated. The color coding allows group members to keep track of their own ideas. At the end of the writing process, all possible ideas about the topic are generated. This writing technique can be especially useful when reviewing material.

Expository writing assignments can be incorporated into the mathematics college classroom at different levels and to different extents. They can range from writing assignments that can simply be added onto a traditional classroom to writing assignments whose success depends on a complete shift from instructor-centered to student-centered classroom. The defining property that these assignments share is that they give the students the opportunity to expand and to reflect on their learning and to connect different concepts and ideas, while at the same time learning to apply (informal and/or formal) writing techniques within the discipline.

Expressive Writing Ideas

These writing assignments are the most creative types of writing in the mathematics classroom. Just like the expository ones they can vary from the informal (e.g. stories, songs, or problems) to the formal (models, formal systems, study reports). They typically involve students constructing or creating a mathematical application of some type. The purpose of these assignments is to provide students with opportunities to synthesize and to internalize mathematics knowledge by making it their own, through the process of creating a new product around specific mathematical concepts. Due to their creative nature, these assignments perhaps result

in the highest degree of sense-making from all three types of writing, but they are also the most difficult to generate, to execute, and perhaps to evaluate. Typically for these assignments, students need to choose a topic they want to explore and the methods for their exploration. They need to research sources beyond their class material and demonstrate flexible thinking about possibly open-ended questions. Problem and test writing items excluded, perhaps most instructors will choose to relegate all other expressive assignments to seminar type courses and upper level major courses, where more time and resources can be dedicated to making these assignments a central part of the learning process.

In expressive assignments, students can create word problems around a specific mathematics topic (e.g. systems of linear equations with two unknowns) or write exam questions. Students can also research and construct their own applications of course material or write a report about mathematical models they built or a study they designed and carried out. They can write about proofs they constructed or new patterns they discovered. Defining the audience for these expressive assignments is very important, and it can predetermine the level of formal writing required: it matters if the student is writing for a peer, the instructor in the course, or a mathematics journal.

A Word on Assessment

Effective assessment practices in mathematics should inform instruction, and well-designed writing assessments can do so by providing invaluable information about students' understanding of mathematical concepts. One remaining challenge is the evaluation of writing assignments in mathematics. The beginning, informal assignments can be simply checked off for completion, but as the depth and breadth of writing increases, so does the need for appropriate assessment. Most mathematics professors are only comfortable using a points system of grading. Thus, rubrics for

evaluating writing can be especially beneficial. The simplest of these rubrics is based on a 3-point system: 1 for students who "missed the boat," 2 for students who "are on the right track," and 3 for those who "got the point." Another simple rubric contains four components: mathematical accuracy, completeness, clarity, and language use. For each component, a student might receive a score of 1, 2, or 3, corresponding to minimal, emerging, and thoroughly developed. Every instructor could modify these suggestions or create a rubric tailored to the specificities of the writing assignment. Three actual writing assignments and their rubrics are included in the Appendices A, B and C.

Conclusion

Writing assignments constitute one of the important ways an instructor can get students actively involved with the material they are learning in any college course. As a discipline that requires constant revisiting and connection of ideas and a need for clear organization, justification, and rigor of thinking, mathematics presents a natural venue for exploring the possibilities of writing both inside and outside of the classroom. The benefits of using writing can include not only gains in students' learning that stretch beyond mathematics content into the realm of critical thinking, but also overall improved attitude, success rates, and retention. This article is meant to give the reader a taste of the possibilities, without trying to be exhaustive, and to inspire instructors in all disciplines to contemplate incorporating writing in the college classroom. ■■

Appendix A

Comparing Different Geometries: Project Guidelines

Working as a group, you will investigate a problem or idea from taxicab or spherical geometry (or both) and, if appropriate, relate your results to Euclidean geometry. Each group will write a detailed report of their discoveries and will create a poster to display their work from the project and present it to the class on Thursday or Friday of the last week. Presentations should be about 15 minutes, including a few minutes for questions.

It is expected that your work on this project will show:

- understanding of the mathematical concepts and processes.
- where appropriate, clear evidence of doing purposeful mathematics, including investigating, experimenting, analyzing, or solving.
- mathematical supporting arguments that may include examples or counter-examples.
- creativity and thoughtfulness in communicating the results and the interpretations of those results, to the appropriate audience (your classmates), using dynamic and diverse means.
- a high level of mathematical thinking that includes, where appropriate, making comparisons, conjectures, interpretations, predictions, or generalizations.

SOME POSSIBLE PROJECT TOPICS

Topics in taxicab geometry:

1. Investigate the results of adding one-way streets.
2. Investigate the results of adding a mass transit route.
3. Investigate taxicab geometry if the streets are laid out in a triangular grid (or on another regular or semi-regular tessellation of the plane.)
4. Investigate/compare ellipses and other conic sections in Euclidean and Taxicab Geometries.
5. In Taxicab Geometry, investigate Euclidean congruence theorems (such as Side-Angle-Side.)

Topics in spherical geometry:

1. Explore the relationship between angle sum and area.
2. A polar triangle is defined to be a triangle that contains a pair of polar points as two of its vertices. Explore the properties of altitudes, angle bisectors, and perpendicular bisectors of its sides in a polar triangle.
3. Investigate the geometric properties of globe that are preserved by a cylindrical projection.
4. Investigate measuring area of spherical triangles and other spherical polygons.
5. Investigate the Platonic solids and their resulting tessellations on the plane.
6. Investigate on the sphere the analogs of the following Euclidean transformations: reflection (flip), rotation (turn), translation (slide), and glide-reflection (slide-flip).

GEOMETRY PROJECT SCORING RUBRIC

Names of group members: _____

| Category | Exemplary 4 | Accomplished 3 | Developing 2 | Beginning 1 | Score |
|--------------------------|--|--|---|--|-------|
| Communication | Mathematical ideas are presented in a highly effective manner, using correct vocabulary, symbols, and/or pictures. | Mathematical ideas are presented effectively, using correct vocabulary, symbols, and/or pictures. | Some mathematical vocabulary, symbols and/or pictures are used ineffectively or incorrectly. | Many mathematical vocabulary words, symbols and/or pictures are used ineffectively or incorrectly. | |
| Doing Mathematics | Clear evidence of doing purposeful accurate mathematics, including investigating, experimenting, analyzing, solving, comparing, conjecturing, and/or generalizing. | Evidence of doing purposeful accurate mathematics, including investigating, experimenting, analyzing, solving, comparing, conjecturing, and/or generalizing. | Some evidence of doing purposeful accurate mathematics, including investigating, experimenting, analyzing, solving, comparing, conjecturing, and/or generalizing. | Minimal evidence of doing purposeful accurate mathematics. | |

| | | | | | |
|------------------------------------|---|---|--|--|--|
| <p>Oral Presentation</p> | <p>Highly organized. Thoughtfully prepared with specific audience in mind.</p> | <p>Well organized. Appropriate to the audience.</p> | <p>Some parts are disorganized. Not all parts are appropriate for the audience.</p> | <p>Disorganized or incomplete. Inappropriate for the audience.</p> | |
| <p>Creativity</p> | <p>Project explores ideas in depth showing creative connections and reflective thought.</p> | <p>Project explores ideas showing some creative connections and reflective thought.</p> | <p>Project explores only a few ideas showing some creative connections and reflective thought.</p> | <p>Project shows minimal evidence of exploring ideas or showing creative connections and reflective thought.</p> | |
| <p>Sharing the Workload</p> | <p>The workload was divided and shared equally by all team members.</p> | <p>Most team members contributed their fair share of the workload.</p> | <p>Most team members participated in some aspect of the work, but workloads varied.</p> | <p>The workload was not divided equally and few team members contributed their fair share.</p> | |

Appendix B

Formal Mathematical Writing for a Peer

Your friend at Rival University is taking a proofs course. He is very confused about sets and their operations (unions, intersections, complements, difference). He cannot even begin to understand De Morgan’s laws. Write a two-to-four page letter to him explaining thoroughly the concepts of sets and their operations. You should definitely include plenty of examples to illustrate your points. Also, you might want to use Venn diagrams to aid your friend’s understanding.

Assessment: Your writing assignment will be graded according to the following rubric:

- ❖ Mathematical Accuracy: 1(inaccurate) 2(minor mistakes) 3(completely correct)
- ❖ Completeness: 1(minimal) 2(in development) 3(thorough)
- ❖ Clarity: 1(minimal) 2(in development) 3(great)
- ❖ Language and Neatness: 0(needs work) 0.5 (in development) 1(excellent)

Appendix C

Portfolio Assignments

There will be six portfolio assignments during the term. These will be problems that each of you will write with the task of illustrating a particular prescribed problem solving strategy. These problems should have at least three different mathematical steps to them! Try to make the problems interesting and relevant to children's lives, and thus useful for you upon entry into the teaching profession.

Have fun and use your imagination!

INSTRUCTIONS: Write your very own multi-step story problem that can be solved and will be solved most effectively using the prescribed problem solving strategy below:

- a. Portfolio 1 : draw a diagram or use a picture (choose one of these strategies or the other!)
- b. Portfolio 2 make a list of all the possibilities or eliminate possibilities (choose one of these strategies or the other!)
- c. Portfolio 3 : guess and check
- d. Portfolio 4 : use sub-problems or patterns (choose one of these strategies or the other!)
- e. Portfolio 5 : use algebra
- f. Portfolio 6 : use Venn diagrams

Please organize your writing in the following format: Problem, Prescribed Strategy, Solution, Verification, Comments for Teachers. The Comments for Teachers section can include ideas for (a) extending or generalizing the problem, or (b) reflective comments about which topics this problem illustrates within the K-12 mathematics curriculum.

The entire portfolio problem is assessed on a scale of 20 points.

Prescribed Strategy: Two (2) points are given for specifying which problem solving strategy your problem is illustrating.

Problem: Ten (10) points are given for this section of the assignment which contains the wording of the actual problem:

- Two (2) points are given for a problem that can be best solved using the prescribed strategy in the assignment.
- Two (2) points are given for writing a problem that illustrates an important mathematical idea.
- Three (3) points are given for an interesting story.
- Three (3) points are given for clarity and good use of language.

The remaining thirteen (13) points are assigned as follows:

- Six (6) points for a complete and correct Solution.
- Four(4) points for Verification.
- Three (3) points for the Comments for Teachers section.

IMPORTANT: Please type and staple one of the scoring sheets below to each of your portfolio assignments:

| Portfolio Problems Scoring Guide | | | | | | |
|----------------------------------|-------------------|---|-----|---|-----|------------|
| Category | Possible Score(s) | | | | | |
| Strategy | 0 | | 1 | | 2 | |
| Problem | | | | | | |
| Appropriateness | 0 | | 1 | | 2 | |
| Math idea | 0 | | 1 | | 2 | |
| Story | 0 | | 1 2 | | 3 | |
| Clarity & language | 0 | | 1 2 | | 3 | |
| Solution | 0 | 1 | 2 | 3 | 4 | 5 6 |
| Verification | 0 | | 1 2 | | 3 4 | |
| Comments for Teachers | 0 | | 1 2 | | 3 | |
| Total: | | | | | | /25 |

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