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Implementing a curiosity-focused hands-on tolerancing activity in a first-year graphics course

Dr. Kellie M Halloran, University of Illinois at Urbana - Champaign

Kellie Halloran is a Teaching Assistant Professor in Mechanical Science and Engineering at the University of Illinois Urbana-Champaign. She holds a BS, MS, and PhD in Mechanical Engineering from the University of Illinois and is currently investigating ways to engage undergraduate students and encourage curiosity and creativity in larger engineering classes.

Dr. Keilin Jahnke, University of Illinois Urbana-Champaign

Dr. Keilin Jahnke is a Teaching Assistant Professor in Innovation, Leadership and Engineering Entrepreneurship in The Grainger College of Engineering at the University of Illinois Urbana-Champaign.

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Abstract

This evidence-based practice paper details the implementation of a curiosity-focused tolerancing activity in a large first-year engineering graphics course. Many first-year engineering courses focus on CAD and engineering graphics, which are important skills for engineering students to learn early in their education and apply in future design courses and projects. As real-world engineering problems grow increasingly complex, preparing future engineers requires equipping them with both technical expertise and the curiosity needed to develop creative solutions. When classes can incorporate curiosity and creativity-targeted activities, students feel a stronger sense of motivation and are subsequently more equipped to solve problems.

This paper investigates a curricular intervention delivered in a first-year course that primarily focuses on CAD and engineering graphics, with an enrollment of over 400 students annually. This course includes both a large lecture and discussion sections. The smaller discussion sections consist of 40 students and allow for more discussion and interactions between course staff and students.

One of the topics of this course is dimensioning and tolerancing according to engineering drawing standards, where students learn about nominal sizes, tolerances, and how to read engineering drawings to interpret part size and interactions. It has been noted that many students in this course struggle to connect theoretical concepts of dimensioned tolerances and fits with how parts actually interact in physical assemblies. To address this challenge, and to spark curiosity about tolerancing and fits, a new lab module was developed in which students calculate and predict the fits of pegs of various sizes inserted into machined holes of different dimensions on a physical board.

In the lab module, students work in pairs to predict which combinations of holes and pegs will fit and how tight the tolerance will be. They practice reading engineering drawings, determining upper and lower dimensional limits from manufacturer specifications, and comparing their theoretical calculations with real pegs and holes to develop an intuitive understanding of how different fits feel in practice. They are then encouraged to reflect on what they've learned and how it might apply to the rest of the course content and the semester-long design project. This module was implemented in the first-year engineering graphics course, and student perceptions were collected using surveys administered following the activity. This paper discusses the findings from the pilot implementation of this module, and future work involves developing more curiosity-focused activities in the course. This lab module can be replicated in similar introductory courses of varying sizes and scope as a means to enhance student curiosity and provide a hands-on learning opportunity. By encouraging curiosity in engineering courses, we aim to not only improve students' technical understanding of engineering concepts but also develop their ability to approach open-ended design problems with curiosity and creativity.

Introduction

As real-world problems become more intricate, training the future generation of engineers involves equipping them with the knowledge and skillsets needed to develop novel, impactful solutions. Complex problems require creative solutions, and students' creativity is linked to their curiosity [1, 2]. Therefore, part of teaching students how to be creative should involve encouraging their curiosity. Curiosity has been identified as one of the key components of an entrepreneurial mindset which is an increasingly valuable skill for students to develop [3]. Additionally, curiosity is associated with higher self-efficacy in students during a semester-long design project [4]. One way to increase students' curiosity is through hands-on learning activities [5], which involve objects that students are encouraged to look at or touch as they are learning about a topic [6]. Hands-on activities are also associated with increased motivation, self-efficacy, peer collaboration, and academic performance [7, 5, 8].

Group activities can be beneficial for student learning, and research shows that peer discussion following demonstrations is helpful for improving student learning [9]. Additionally, students who make predictions before a demonstration improve their understanding of the course topic compared to just observing the demonstration alone [9]. Therefore a key component of a physical demonstration or activity is asking students to make predictions and work with their peers to discuss those predictions both before and after the demonstration.

Many first-year design courses emphasize the engineering design process and computer-aided design as early tools that can be used by first-year engineering students to create prototypes and designs. One of the topics commonly covered by these introductory design and graphics courses is tolerancing and choosing appropriate sizes for parts. However, dimensional tolerances can be a difficult topic for students to grasp and apply to real-world scenarios [10].

There is an opportunity to develop curiosity-focused hands on activities for first-year engineering students that encourage them to think about the content they are learning, and apply it in various ways. Therefore, the purpose of this study was to develop and assess a curiosity-focused group activity for a first-year engineering graphics course. We focused specifically on tolerances and fits, as this is often a topic that students can struggle to visualize and understand. Students worked in pairs to complete and reflect on the tolerancing activity, and a short survey was administered and analyzed to determine the impact of the activity on students' understanding of tolerances and their confidence in applying this understanding to their semester-long design project.

Methods

This study was classified as non-human subjects research by the University of Illinois Institutional Review Board (#IRB25-1271). All participants in the study gave informed consent before their data was used in this analysis.

Course Information

The course of interest for this study was a large first-year computer-aided-design (CAD) course. Enrollment for the Fall 2025 semester was 331 students, primarily composed of first-year students. This course consists of twice-weekly lectures and weekly lab sections. In lecture, topics such as the engineering design process, sketching and drawing, CAD design, design for manufacturability, engineering drawing standards, and tolerances are covered. In lab sections, students have the opportunity to practice CAD skills and complete hands-on group activities in a smaller (maximum 40 students) environment.

During the tolerancing lectures, students learn how to calculate allowance and clearance between two mating parts and how to use the ISO system of limits and fits to set tolerances. They also learn how to classify fits as “clearance,” “transition,” and “interference” fits. However, there were no hands-on activities in which students explored how these fits physically feel. Additionally, there is a semester-long team design project in which students are tasked with redesigning a mass-produced consumer project. One of the requirements for the semester project is that parts designed by the students are toleranced correctly and appropriately given the materials and function of each part. Therefore this course provided an opportunity to build curiosity early in students’ careers, and also to introduce a tolerancing activity that could be helpful for the final semester project and beyond as they continue into upper-level design courses. The tolerancing plate was manufactured at the University’s machine shop.

Tolerancing Activity

Students completed a tolerancing activity in which they were given an aluminum plate with 10 holes of various sizes (Fig. 1). 5 of the holes were created using reamers in metric dimensions, near 6mm in diameter (Holes M1-M5, Fig. 1). 5 of the holes were created with reamers in the imperial system, near 0.25in in diameter (Holes I1-I5, Fig. 1). A full list of the reamers used to create the holes can be found in Table 1. A complete engineering drawing of the plate used for manufacturing can be found in the Appendix.

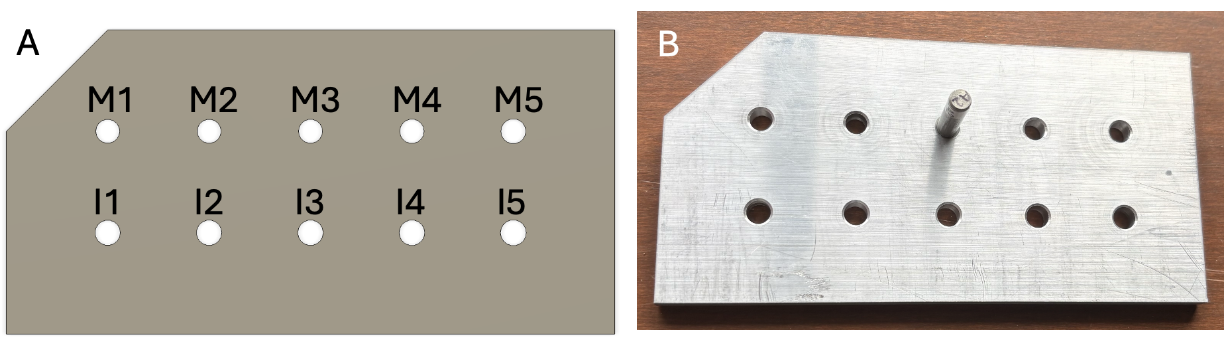

Figure 1: A) CAD model of tolerancing plate. Holes M1-M5 are around 6mm in diameter, and holes I1-I5 are around 0.25 in in diameter. B) Physical plate, with the dowel 2 inserted into the M3 hole.

Students were given various metric and imperial dowels with nominal sizes near 6mm and 0.25 in, and asked to use the manufacturer’s website of each dowel and reamer to calculate the allowance and clearance of each hole and dowel combination (Table 2).

After students had determined the tolerances for each of the holes and reamers, they were asked to calculate the expected fit for each hole and dowel combination (metric dowels in metric holes, and imperial dowels in imperial holes). Following the calculations, students were able to test their expectations against the physical dowels and holes. Students were encouraged to think through

Table 1: Metric and Imperial reamers used to create holes.

Reamer	Nominal Size	Manufacturer	Part Number
M1	5.990 mm	MSC	36233112
M2	6.000 mm	McMaster	8851A21
M3	6.020 mm	MSC	36233104
M4	6.100 mm	MSC	36255776
M5	6.250 mm	MSC	36259349
I1	0.249 in	McMaster	3087A53
I2	0.250 in	McMaster	2995A65
I3	0.251 in	McMaster	3087A33
I4	0.252 in	McMaster	8803A482
I5	0.255 in	McMaster	8803A488

Table 2: Metric and Imperial dowels.

Dowel	System	Size	Manufacturer	Part Number
1	Metric	6mm	McMaster	91585A668
2	Metric	6mm undersized	McMaster	97049A328
3	Imperial	0.25in oversized	McMaster	98985A431
4	Imperial	0.25in oversized	McMaster	99010A201
5	Imperial	0.25in	McMaster	98381A550
6	Imperial	0.25in undersized	McMaster	98105A219

their predictions, and be curious about what they expect physical fits to ”feel” like. There was a short reflection at the end where students were asked to think about the expected fits and the ”feel” of each hole and dowel combination.

Assessment

An optional, non-graded 7-question survey was administered following the activity. All data was plotted in R (v. 4.4.2). The survey was composed of 5-point Likert-style questions, which included:

1. How did your team work together to complete the tolerancing activity? (Scale of entirely individually to entirely collaboratively as a team)
2. How much did you know about tolerancing, limits, and fits before taking ME 170? (Scale of nothing to a great deal)
3. To what extent did your understanding of tolerances, limits, and fits grow as a result of completing this activity? (Scale of not at all to a great deal)
4. As a result of this activity, I am more confident in my ability to analyze how tolerances affect part function and assembly. (Scale of strongly disagree to strongly agree)

5. As a result of this activity, I am more confident in my understanding of tolerancing and hole limits and fits. (Scale of strongly disagree to strongly agree)
6. How helpful do you feel the content you learned in this activity will be for your future career as an engineer? (Scale of not at all to extremely)
7. As a result of this activity, I feel better prepared to justify the tolerances and fits used in my design project. (Scale of strongly disagree to strongly agree)

Results

115 students completed the survey and gave informed consent. Students generally knew nothing (38%) to a small amount (25%) about tolerancing, limits, and fits before taking the course (Fig. 2A). After completing the activity, a majority felt that their understanding of tolerances, limits, and fits, grew by a moderate amount (33%) to a good amount (38%), with 17% of students saying their understanding grew a great deal as a result of the activity. A few students (12%) noted that their understanding grew by a small amount or not at all (Fig. 2B).

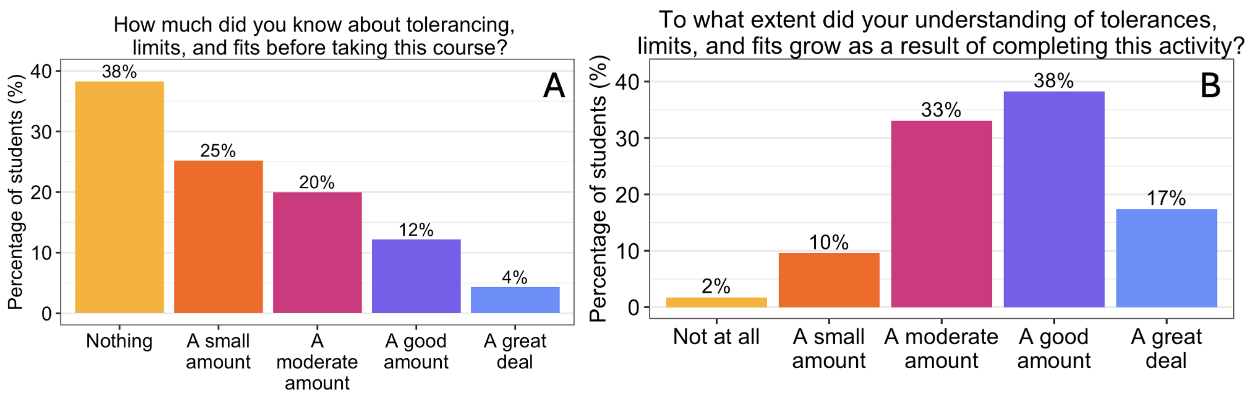

Figure 2: Likert-style questions about A) prior tolerancing knowledge and B) growth in understanding of tolerances. (n=115)

We were also interested in examining the level of collaboration used by students to complete the activity. A majority of students used some combination of collaboration and individual work to complete the activity, with 34% using some division of work with some collaboration, and 34% using mostly collaboration with some individual contributions (Fig. 3). Some students (16%) completed the activity entirely collaboratively as a team, and some (16%) completed it mostly or entirely individually.

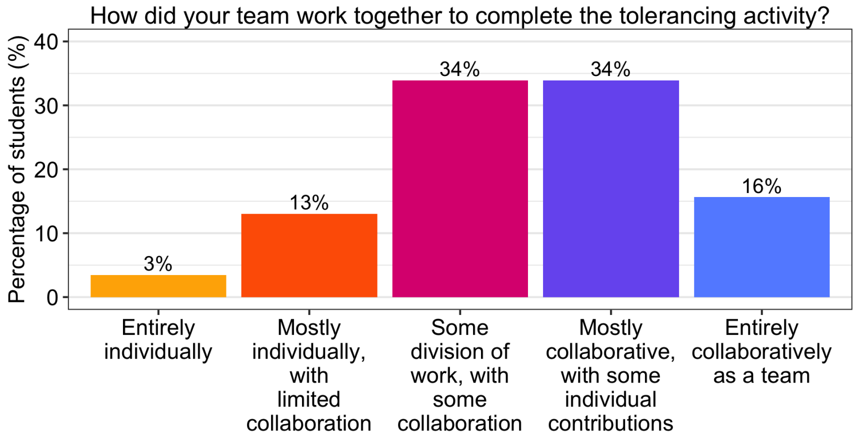

Figure 3: Likert-style question about how students worked together to complete the activity (n=115).

To determine the change in students' self-efficacy following the activity, we collected data related to students' confidence in their understanding of tolerancing and tolerancing topics (Fig. 4). Most students felt that the activity made them more confident in their understanding of hole limits and fits (55% somewhat agree and 31% strongly agree, Fig. 4A). Most also felt that the activity made them more confident in their ability to analyze part tolerances in an assembly (55% somewhat agree and 32% strongly agree, Fig. 4B).

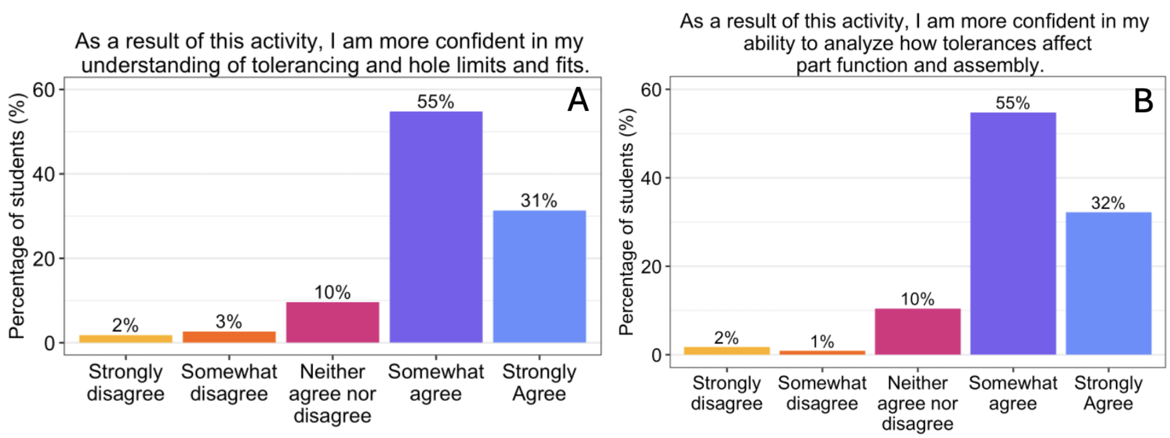

Figure 4: Likert-style questions examining students' confidence in tolerancing and related topics (n=115).

Lastly, we asked questions related to students' perception of how the content from this activity could be applied to their semester-long design project and their careers in general. Long term, all students felt that the content from the activity would be at least slightly helpful in their future careers, with 37% feeling it would be moderately helpful, 35% indicating it would be very helpful, and 14% feeling it would be extremely helpful (Fig. 5A). Similarly, 81% of students felt that the activity prepared them to justify the tolerances and fits required for the semester-long design project (Fig. 5B).

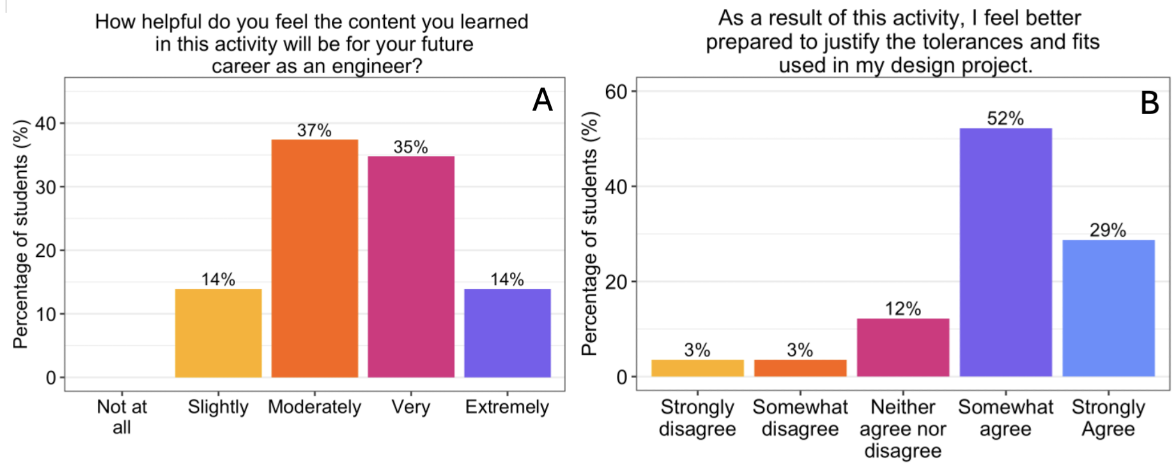

Figure 5: Likert-style questions examining students' perceptions of activity applications (n=115).

Discussion

It was not surprising to learn that most students had little knowledge of tolerancing, limits, and fits before taking the course, and it was encouraging to see that the activity led to a moderate to large increase in students' self-reported understanding of the course topics. It is evident that the activity does help students understand tolerancing, and we plan to continue to develop it in future iterations of the course.

While the assignment was designed to be completed collaboratively in teams of two or three, students were split on the level of collaboration that was actually used to complete the activity. While 50% of students completed it with more collaboration than individual work, 16% completed the activity with more individual work than collaboration, with 34% reporting that the work was split. Collaborative skills are an important aspect of ABET outcomes, and are also necessary skills to develop for the engineering workforce [11]. There is an opportunity to continue to adjust the framing and structure of the activity to encourage more students to work collaboratively together. Collaboration could be particularly helpful in a first-year class where students are meeting classmates and beginning to build connections with their peers. A more detailed analysis of learning outcomes after the activity could clarify whether students who worked individually missed key aspects of learning when those tasks were completed by their team members.

Students' self-reported confidence in their understanding of tolerancing and fits and their ability to apply their knowledge to assemblies generally increased as a result of completing this activity, which is a promising outcome.

Open-ended reflection questions at the conclusion of the activity were designed to encourage students to consider how their learning could inform future design projects within the course and beyond. Every student agreed that the content they learned would be at least slightly helpful for their future careers, with most saying it would be moderately to extremely helpful. In addition, a majority of students (52%) somewhat agreed to feeling better prepared to justify tolerances in their semester project. While students do feel more comfortable applying limits and fits to their final design project, there is some room for improvement here. Currently, we only ask students to reflect on applications in a broad sense. Future iterations of this activity could ask students to specifically analyze their semester project in light of the information learned in the activity. This could facilitate connections between the tolerancing activity and the final design project.

Limitations

While this is a helpful first step in analyzing the impact of a curiosity-focused tolerancing activity, there are some limitations to our analysis. First, all of the analyzed data is self-reported measures of student learning, which could either be biased or not fully reflect students actual learning following the activity. Second, only 35% of students completed the optional survey following the activity. While we still have a relatively large sample size (n=115), this number may not accurately reflect the entire population of the course. Future analyses could use various methods to recruit a higher percentage of the class to ensure that survey responses are an accurate representation of the course as a whole.

Conclusion

Introductory computer-aided design courses can offer students not only an opportunity to learn foundational knowledge but also to enhance their overall curiosity and interest in the topic. Providing hands-on activities are a proven pedagogical method to do this, and this paper described the efficacy of one such activity. Similar courses can utilize a university or local machine shop to construct a low-cost tolerancing plate that can then be used during lab sessions for students to actually ”feel” and experience how tolerancing decisions impact physical designs. By incorporating a physical tolerancing plate and activity into either part of or an entire class session, students in introductory design courses can more firmly grasp the concept of dimensional tolerances and apply it to course projects and subsequent real-world scenarios.

Acknowledgements

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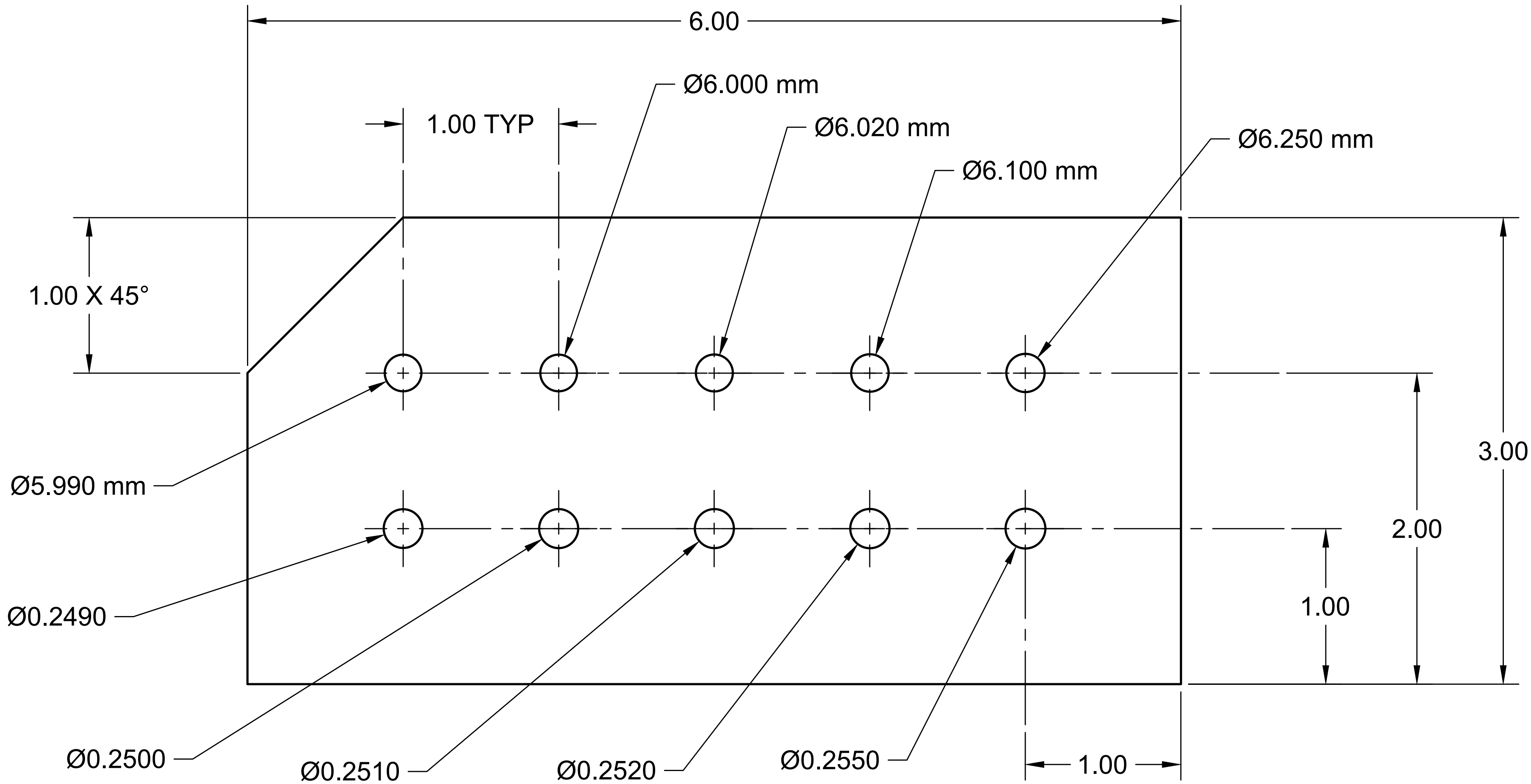
Supplemental Data

Engineering Drawings

An engineering drawing used the create the plate can be found on the following page.

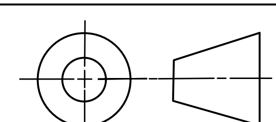


0.002" CHAMFER ON ALL HOLES
THIS SIDE AND ALL PLATE EDGES

0.25" THICK ALUMINUM

UNLESS OTHERWISE SPECIFIED
DIM ARE IN INCHES
TOL ON ANGLES ± 1°
2PL ± 0.03 3 PL ± 0.005
INTERPRET DIM AND TOL PER
ASME Y14.5M- 2018

THIRD ANGLE PROJECTION



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Title: Tolerance Example Sheet_Smaller

Size	Material	DWG NO	Rev
A	Aluminum	1	

Scale	Drawn By	Date	Sheet No.
1:1	Kellie Halloran	12/16/24	1/1