A Holistic Approach to Engineering Training: Applying Tolerance Analysis, GD&T, and Dimensional Management

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**Abstract**

In the ever-evolving landscape of engineering, manufacturing & CAE, the cornerstone of excellence consistently rests upon the robustness of processes and the proficiency of skills within teams to ensure precision, efficiency, and reliability.

In an era marked by rapid innovation, complex project scopes and growing teams with hybrid working environments across the globe, traditional training’s inadequacy to fill the skill gaps in engineering teams has become evident. Fostering a strong core foundation of engineering skill not only ensures that those quality needs are met by their products, but reduces business costs to contribute to sustainable success.

Often courses are taught in isolation and don’t utilise knowledge gained elsewhere in order to maximise the capability of their trainees. Segmented training courses result in a holistic understanding not being developed.

If multiple training courses are led by the same provider, each training course can lead on from its predecessor, allowing case studies shared by the trainees to be explored in their entirety all interrelated requirements simultaneously.

This is particularly significant with respect to mechanical variation, with three key pillars supporting a complete quality package. Tolerance Analysis, Geometric Dimensioning & Tolerancing (GD&T), and Dimensional Management must be applied to ensure that designs are cost effective and functional. Using GD&T definitions requires the impact of those tolerance definitions to be understood through 3D statistical Tolerance Analysis, and the implementation of both of those methodologies through Dimensional Management is key to cost and project workflows.

This presentation explores the application of multi-disciplinary training with respect to those three disciplines, where engineers will learn the benefits of a holistic training program that is tailored to their specific needs. We will outline the process we used to develop material & enable this approach to facilitate the development of the next generation of simulation capability in engineers.

# Introduction

GD&T, Tolerance Analysis and Dimensional Management are three pillars that together constitute a total package in relation to product quality. Each discipline can be considered individually, but are closely interlinked in a way that having knowledge of all three disciplines and an understanding of how to work with them simultaneously is the only way to provide maximum benefit of the topics discussed in the courses. Training courses can be developed in order to provide trainees with a range of tools that they can pick and choose from among those three pillars, but there is not always clear direction in the specific tool, or combination of tools, that would be of most benefit to meet particular requirements or business goals at any given moment. This results in who understand the concepts, but do not necessarily know how to implement those methodologies to move the company forward in the most efficient way.

Integrating those methodologies improves the outcome even further. Performing a Tolerance Analysis study requires an understanding of the variation specified on a drawing. If any GD&T is being used, the Tolerance Analysis calculations must accurately represent the variation provided by the methodology described on the drawing. A lack of understanding of GD&T during the Tolerance Analysis stage will lead to miscalculations or errors in the study. The engineer applying the GD&T to the drawing must be able to understand the Tolerance Analysis process in order to communicate design intent and mitigate the impact the variation has on the functional requirement analysed in the TA study. A semantically correct GD&T definition does not inherently promise quality. This can lead to a misplaced confidence if a strong understanding is not developed.

Finally, tying together GD&T and Tolerance Analysis informs business analysis of the outcomes and is the foundation of Dimensional Management. If a manufacturing process is not cost effective, then the product cannot be made in the required quantity while maintaining the same level of quality. Training employees effectively to ensure each team member has the right skillset is challenging when the topics are so heavily interlinked. In the same way that we must optimise cost, time and functionality in our manufacturing, the training courses themselves must also optimise cost, time and functionality.

# Current Status of GD&T, Tolerance Analysis and Dimensional Management

Ensuring product quality involves a number of steps. The first is being clear in the communication of the design intent. Then it is essential to make sure that the drawings themselves are communicating a level of acceptable variation that doesn’t hinder product quality. The last step is ensuring that same level of product quality while minimising manufacturing and design costs.

To achieve this, the drawings must be clear and understood by all employees who are required to view it in the same way, however not everyone’s understanding is the same. Companies sometimes end up adopting a ‘house style’ that is jointly understood by both manufacturing and design teams, but is inherently different to what is expressed in ISO standards. This poses challenges not only to the quality of the products, as the tools might not be being used to their full potential, but also runs the risk of new employees or suppliers being brought in that have a different understanding of the concepts. This could not only pose a critical issue to the functionality of a product, but also invalidate testing and analysis.

Designing to manufacture has been a long-running challenge. The ever-expanding world of simulation and digital design is resulting in more complex product design to accommodate aerodynamics, topological optimisation and other intricacies to provide a competitive edge. These features require more in-depth definitions on a drawing to ensure that the manufacturing instruction is clear while ensuring product quality and limiting functional variation. This makes the GD&T required to define the features properly more complex, and 1D Tolerance Analysis will no longer suffice as 2D and, more commonly nowadays, 3D effects are required to be taken into account.

# Customised Training

The process to achieve the desired level of expertise might not necessarily be identical between companies.

In smaller companies, engineers are more often having to perform a range of tasks within their job role, with each employee requiring a range of training courses to meet their needs. In larger companies it is more common, although still not guaranteed, that each employee will have a specific role to perform, with a wider team effort coming together to cover all methodologies and processes.

Companies might also differ in terms of location and availability. Firms might be spread across multiple sites, individual employees will have varying levels of availability, and hybrid working being more commonplace results in less people being in the same place simultaneously. Finding a suitable timeslot to gather everyone in a room for potentially 2 to 3 consecutive days is not an easy challenge, and can delay training further.

Combining a range of training courses into a whole package solidifies the understanding against the business requirements while keeping customer satisfaction at the core of the process.

# Delivery of Course Material

It is likely that each employee will specialise in one of the three pillars of GD&T, Tolerance Analysis and Dimensional Management, but to only train them in one discipline would do both them and the company a disservice. It is imperative that each employee must have a suitable level of understanding of each topic for their job role. The training offerings must therefore reflect this desired outcome.

A combination of ‘Introduction’ courses and ‘Advanced’ courses should be available to all engineers. Introduction courses should act as a leveller to ensure each employees understanding of a topic is the same, and should be undertaken by all engineers. The leveller courses would be of more benefit to be online. Online training allows all trainees to complete the programme around their own schedules, without requiring all members to be present simultaneously.

Advanced courses will focus on the key business requirements and implementation of the knowledge to meet customer requirements, as well as delve further into the topic. These should be specialised courses with smaller class sizes, allowing individuals to focus on a key area. Advanced training courses should be in-person to facilitate discussions between the trainer and trainee, as well as offer the chance for worked examples using customer data to occur within the training session. This provides direct support from the trainer on the engineer’s challenges, ensuring an easy transition to the application of the knowledge post-training. The smaller class size on advanced courses compared to the leveler courses keeps training organisation to an acceptable amount also.

The variety available between online courses and in-person courses also allows for the tailoring of each individual’s preferred style of learning. The four types of learning are Visual, Auditory, Reading/Writing and Kinesthetic (Fleming, 2019. The online training includes visual (images, custom animations), auditory (voice narration) and reading. The in-person training covers visual (slides, videos), Auditory (direct from the trainer), Reading/Writing (slides) and Kinesthetic (software exercises, physical model demos).

A number of engineering businesses have benefitted from this combination of online and in-person training courses and were able to solidify all employees understanding the wider concepts whilst also selecting key individuals to specialise in a given subject. It was felt that the right level of training was applied to each employee without overloading any one team member.

# Pre and Post Training Support

Prior to the course, trainers should familiarise themselves with the key required outcomes of the customer. This provides a greater learning experience for the trainees, whilst maintaining that the business goals are kept at the forefront of the conversation. Spending time prior to the training to iron out the key challenges related to the subject, having the customer share materials (drawings, CAD files etc) prior to the training for the trainer to review and plan around and engaging with the trainees in a workshop focused around their challenges ensures the trainer has the ability to apply their expertise to the challenge. Additionally, if the courses are provided by the same provider, the details of progress from one course can be shared in the next, assuring continuity between courses and aligning the outcomes of the whole process.

Once training has been completed, continuing to provide a range of options to contact the tutor would allow additional opportunities to discuss ideas with an expert. This can include online mentoring, with web calls between the trainer and trainee to discuss progress, share challenges and further explain concepts, as well as in person workshops to allocate time to further in-person support on new technical challenges. This, along with refresher courses, trainees can be reminded of the key aspects to keep in mind to prevent falling back into old habits or forgetting certain aspects of the material. Refresher courses are an excellent opportunity for the trainers to provide additional good practice and specialised examples. The online training platform is ideal for refresher courses to provide trainees with a platform they can keep coming back to whenever the refresher is needed. This is essential in Tolerance Analysis and GD&T as these tasks are not 24/7 tasks, and are often done when necessary on a given project, giving plenty of opportunity for those skills to be lost over time.

# Conclusion

A new, innovative journey of skill improvement has been developed to give customers a supported choice of options that meets engineer’s technical and business needs.

Along with the training providers, engineers and managers should develop a solution tailored to provide the right technical knowledge on an individual basis while optimising the rollout of the training across all teams. By planning who should be being trained on what courses, and when they should be trained, the business requirements are kept at the forefront at all times.

# References

Fleming, Neil (2019). *Vark Strategies: The definitive guide to VARK:* Kindle Direct Publishing