CAE Variants Analysis at Rheinmetall Automotive. A Success Story.

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Abstract

This paper provided an insight into optiSLang history at Rheinmetall Automotive simulation department. It depicts why Rheinmetall Automotive had to go into the direction of CAE variants analysis and how it started to raise optiSLang to be an established tool. A glimpse into future activities is provided, too.
This optiSLang history covers less than 10 years. Since Rheinmetall Automotive simulation department is convinced by the advantages performing CAE variants analysis it is willing to share some of its experience in present article. Rheinmetall Automotive simulation department states that ANSYS Dynardo tools provide key functionalities for efficient product development. The more people share and live the spirit of CAE variants analysis inside and outside the company the better for products and processes.

Keywords:
simulation-driven design optimization, optiSLang introduction, introduction challenges, introduction strategy, variants analysis benefits

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1 Introduction

It was challenging to introduce optiSLang on a broad and substantial level but Rheinmetall Automotive was successful within few years. Contribution to success was a close collaboration with ANSYS Dynardo team and the Institute of Modeling and high Performance Computing at Niederrhein University of Applied Science.

Since optiSlang story of Rheinmetall Automotive simulation department is individual, it is necessary to describe the initial situation and the company structure.

1.1 Initial Situation

1.1.1 Organizational Context

Rheinmetall Automotive splits into three divisions:

- Hardparts (trademark "Kolbenschmidt")
- Mechatronics (trademark "Pierburg")
- Aftermarket (trademark "Motorservice", spare parts business)

Divisions Hardparts and Mechatronics deliver solutions for sustainable reduction of emissions as well as for reduced fuel consumption. Their product portfolio is different but many synergies are used. Central simulation department works for both divisions as internal CAE[1] service supplier. Therefore, simulation department is facing a broad spectrum of CAE tasks caused by diverse product portfolio. It covers products for internal combustion engines like pistons, EGR[2] valves and oil pumps. There are also products for hybrid and electrical vehicles like electrical engine housings, coolant valves and bearings. Since hybrid and electric mobility segment will grow in the future, it will influence the task list of simulation department significantly.

Rheinmetall Automotive simulation department hosts 75 CAE engineers, which are located at several international sites. It delivers CAE services as internal supplier to diverse development teams in all business units. In the present article, the focus is on simulation team, which is located in Neuss, Germany, and mainly supports division Mechatronics. This team splits into four groups:

- system and electronics simulation
- FEA[3] and multibody simulation
- CFD[4] simulation
- quality tools (DOORS[5], Automotive SPICE[6,7] etc.)

[1] CAE = computer-aided engineering
[2] EGR = exhaust gas recirculation
[3] FEA = finite element analysis
[4] CFD = computational fluid dynamics
[5] DOORS = dynamic object oriented requirements system (requirements management software)
[6] variant of development process assessment standard ISO/IEC 15504 (SPICE)
[7] SPICE = software process improvement and capability determination

Each simulation group has a staff engineer who is supporting key capabilities of specified groups. There is close collaboration between team Neuss and the foreign Mechatronics simulation sites as well as with Hardparts simulation team. Thus, the simulation network of Rheinmetall Automotive is very powerful and CAE services are broadly diversified.

1.1.2 Motivation

Figure 1 depicts the motivation why Rheinmetall Automotive started with the topic of CAE variants analysis. The left hand side shows the project management triangle, often referred as The Iron Triangle[8]. The axes timing, costs and quality create it. Automotive suppliers are confronted with the situation to overcome the "pick two"-dilemma[9] (black triangle compared to red triangle) because customer asks to further increase quality and raising development efficiency at the same time (blue triangle). This challenges the development processes. The right hand side shows the classical V-model as defined for software development by Barry W. Boehm[10]. It tells a lot about requirements handling and system understanding within software development processes. Since professional handling of requirements is also essential in product and system development[11], classical V-model and its enhancements and extensions are valid for and linked to Rheinmetall Automotive development processes. Thus, precise requirements management creates many development tasks.
In order to fulfill both sides (project triangle and V-model, see Figure 1), extensive use of simulation is required to support decision-making. In particular, there is a need for simulation driven design optimization processes to realize a better design-to-customer. Improved design-to-customer requires a profound product understanding, which results in a positive effect on product performance and quality, too.

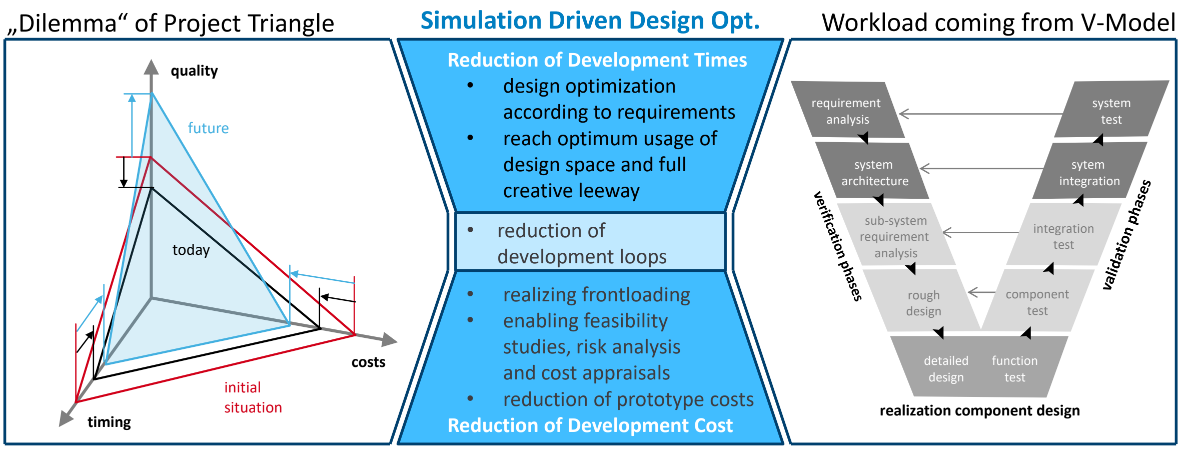

Figure 1: Motivation for simulation driven design optimization

The center of Figure 1 shows the contribution of simulation driven design optimization[12]. Simulation driven design optimization will finally reduce development time because it is a

[8] ATKINSON, R. (1999)
[9] POLLACK et al. (2018)
[10] BOEHM, B. W. (1979)
[11] GRANDE, M. (2014)
[12] JASPER, J. et al. (2013)

straightforward approach to optimize designs according to requirements using the full design leeway. In addition, it will decrease development costs. Assuming variants analysis (which are indispensable part of simulation driven design optimization) is performed early in the project, development team will benefit from all frontloading advantages. There will be a more complete view available on feasibility, risks and costs. Even the number of prototypes and their costs can be reduced. Finally, the potential to reduce development loops with its impact on development costs is essential.

1.1.3 Vision

According to the idea of frontloading, Rheinmetall Automotive simulation department promotes and recommends early simulation[13]. Available software and CAE engineer skills are able to support product development process already in concept phase when only design space and interfaces are known. Optimally, a continuous simulation workflow accompanies the development activities resulting in an optimal and robust design. Figure 2 exemplarily illustrates the schematic draft of such continuous workflow. With given software examples it is applied in CFD tasks by simulation team Neuss. In reality, the workflow is more complex due to adaption loops etc.

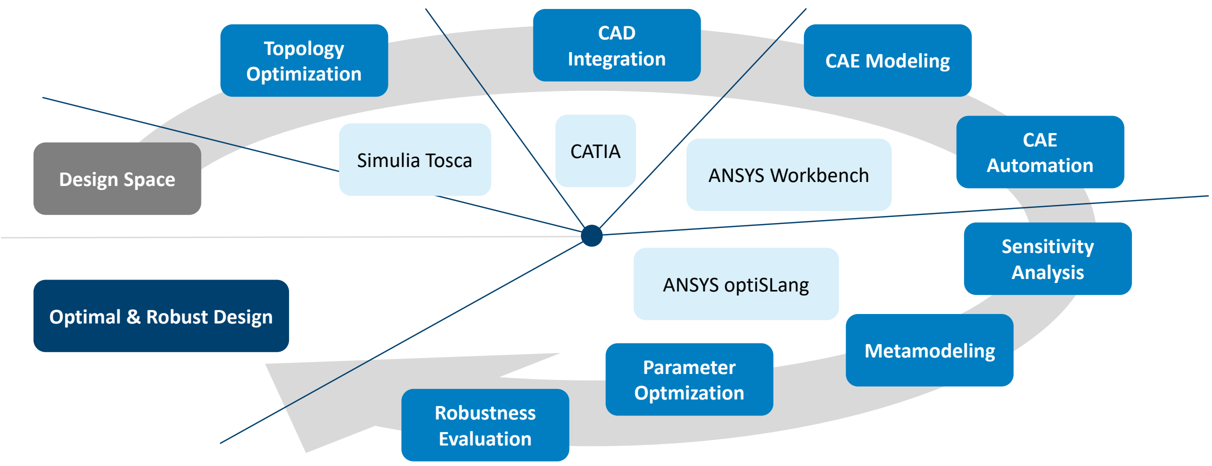

Figure 2: Continuous Workflow from Topology Optimization to Robustness Evaluation (schematic draft for CFD tasks)

Following the arrow in Figure 2, the application of topology optimization based on available design space is the first step. Topology optimization results are implemented into parameterized CAD[14] geometry. ANSYS software tools are used to perform CAE modeling and CAE automation. Finally, optiSLang is used to perform variants analysis and optimization. This workflow boosts innovation and substantiated, straight-forward design improvement. At WOST 2016[15], Rheinmetall Automotive presented results for EGR flap valve coming from this workflow. Improvements of up to 45% compared to reference design were confirmed on testing facility.

[13] SEGGEWIß, P. (2010)
[14] CAD = computer-aided design
[15] THOMAS, T. et al. (2016)

2 First Steps in the Field of CAE Variants Analysis

At the beginning of millennium, Rheinmetall Automotive simulation department faced the situation that the collaboration with design department was “classical”. That means that there was a looping between designer and CAE engineer for each more or less little geometry modification. Parameterized CAD data – especially for sand cast parts – was not usual. In addition, computing performance and technology was on a different level at that time.

Nevertheless, Rheinmetall Automotive simulation department decided to go into the direction of CAE variants analysis and numerical optimization. The idea was to make CAE engineers more independent from design progress and to give them deeper insights into part behavior. One of the enabling technologies was the mesh morphing approach[16].

2.1 The Contribution of Mesh Morphing

In using mesh morphing, CAE engineers modify geometry based on mesh data. Displacement vector fields at mesh nodes realize parameterization – so called shapes. Shapes can be used in variants analysis to capture trends and identify sensitivities. Today, Rheinmetall Automotive simulation department still applies mesh morphing, also for large CFD models in conjugate heat transfer (CHT) context. CHT morphing workflow is applied i.e. in EGR flap valve applications. Different locations at fluid (i.e. coolant channel walls) and solid parts (i.e. cooling ribs) are morphed and varied within a sensitivity study. Such approaches contribute to decision making with regard to efficient material distribution.

2.2 optiSLang Pilot Project and 1st License

Due to the weaknesses and challenges of mesh morphing regarding geometry modification precision, the meanwhile improvement of CAD tools (regarding parameterization) and the availability of an appropriate project, Rheinmetall Automotive simulation department made its first steps with optiSLang around the year 2013. At this time, optiSLang was in focus because of its MOP[17] functionality. Therefore, there was a strong interest in checking optiSLang for suitability. The intention was to challenge optiSLang with a complex optimization task. Hence, a first project was defined in rotating machinery context. The objective was to improve the transient performance of an electrical air compressor. 49 geometry parameters were varied in the DoE[18] with 130 designs. Microsoft Excel and ANSYS Workbench including FEA and CFD solver runs had to be coupled to optiSLang. The project was worked in close collaboration with professor Dirk Roos and his team from Niederrhein University of Applied Science and it delivered impressive results, which have been published at WOST 2015[19]. Optimized design for electrical air compressor provided improved acceleration behavior and a reduced time to torque.

[16] SEGGEWIß, P. (2010)
[17] MOP = metamodel of optimal prognosis
[18] DOE = design of experiment
[19] WANZEK, T. et al. (2015)

Such positive results smoothed the way to Rheinmetall Automotive's first own optiSLang license in 2014. In addition, the project mentioned above became the first flagship project. Next chapter provides more details about this topic.

3 Introduction Challenges and Strategies

Although optiSLang is a powerful tool, Rheinmetall Automotive simulation department had to spend a lot of effort to ensure a successful introduction. Bringing it to daily project application was not always easy. Mainly, it had to do with the three challenges shown in Figure 3.

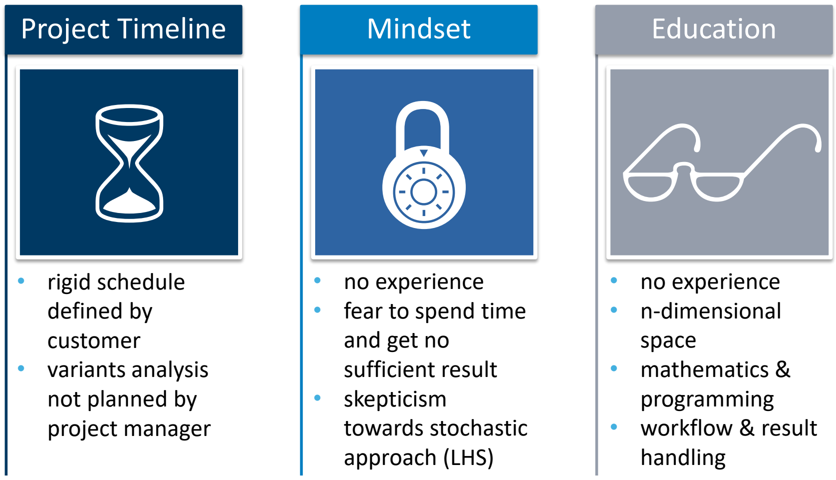

Figure 3: Main Challenges introducing optiSLang at Rheinmetall Automotive

The first challenge is the project timeline. Initially, there was the problem that CAE variants analysis did not fit to the rigid schedules of operative projects. There was no possibility to shift timeslots for CAE to the beginning of projects with the intention to save some CAE loops later. This has to do with second challenge, which is the mindset of project decision makers. Due to the lack of experience with the new method, there was a quite big fear to waste time and money. In addition, there was skepticism regarding stochastic approach used in optiSLang LHS[20]-based sensitivity analysis and towards the power of optimization algorithms. The third challenge to take was the education of CAE engineers. They also had no or weak experience with variants analysis. Thus, building up further skills in n-dimensional analysis, mathematics, programming and handling of workflow and results was essential. However, Rheinmetall Automotive simulation department was willing to accept the challenges and to spend the efforts to get optiSLang running in the company.

3.1 CFD Projects as "Locomotive"

The CFD group of Rheinmetall Automotive simulation department provided the locomotive to get the optiSLang introduction started. Appropriate projects regarding task and timeline were available there. Another reason was the more or less simple way to validate the results of variants analysis and optimization. For example, tests on flow bench provide pressure losses,

[20] LHS = latin hypercube sampling

which are of high interest in engine parts business. In addition, CFD group had very capable student workers at this time who supported the introduction of optiSLang a lot. By working the first CFD optiSLang projects, CAE engineers improved their communication with internal customer. That was important in order to gather all the information regarding constraints and requirements affecting variants analysis. Otherwise, weak communication would have endangered the acceptance of variants analysis result. In addition, CAE engineers improved their strategies for parameterization and efficient convergence. As explained before, introduction process is accompanied by gathering experience for all parties and collecting flagship projects. Flagship projects are a key factor to generate a request for optiSLang orders from internal customers. In addition, they are part of optiSLang PR[21]-strategy that was derived in Rheinmetall Automotive simulation department.

3.2 PR-Strategy

The optiSLang PR-strategy consists of three components:

- flagship projects
- consulting of internal (and external) customer
- method promotion

Rheinmetall Automotive simulation department made the experience that there was the need to define and work flagship projects for almost each development team separately. Transfer and acceptance from other Rheinmetall Automotive products was not always easy going for the development teams. Thus, Rheinmetall Automotive simulation department worked on filling its optiSLang application catalogue with the intention to have appropriate, own examples when being involved in consulting activities. Typically, this is within simulation planning meetings. Another gearwheel of the PR-strategy is more or less pure promotion and advertising using different channels like company internal "Tech Talks" or the simulation department channel in the company intranet "gate2simulation". Not only talking about CAE methods and good results is in focus. Also discussing both with the customer in order to understand their needs. This feedback enables us to further improve and customize CAE processes and analyses.

3.3 Knowledge Management Strategy

Another component for successful introduction of optiSLang is the simulation department internal knowledge management strategy, which consists of three pillars. The first pillar of the knowledge management strategy is the support of ANSYS Dynardo. Yearly "optiSLang info days" and the access to service projects enable knowhow transfer from ANSYS Dynardo experts to CAE engineer as well as effective support in operative projects. The second pillar is that Rheinmetall Automotive established an internal optiSLang coordinator in the simulation department. The coordinator is the contact person for all internal and external optiSLang needs and has the overview about all optiSLang activities and best practices. Hence, the coordinator is the internal support for Rheinmetall Automotive optiSLang users. He is also responsible for method development and for strategy definition in order to further improve and customize workflows for variants analysis, numerical optimization and robustness evaluation. Third pillar

[21] PR = public relations

of knowledge management strategy is the intranet channel “gate2simulation”. There, CAE engineers and the optiSLang coordinator publish news, manuals, scripts etc. for worldwide usage inside Rheinmetall Automotive. One of the next steps is to implement the optiSLang webinterface. This will further improve the distribution of knowledge and usage of optiSLang inside the company. All efforts in knowledge management are spent to keep the error probability low and the learning curve steep. Especially for optiSLang beginners.

4 From scalar MOP to Field-MOP

Having all efforts and strategies from previous chapter in mind, Rheinmetall Automotive simulation department was able to increase the usage of optiSLang significantly within last years. This means that also the number of licenses increased. Figure 4 shows the development schematically.

Figure 4: Development of optiSLang Usage @ Rheinmetall Automotive Simulation Department; Number of Licenses and excerpt of coupled Software

As mentioned before, starting point for optiSLang usage were projects referring to ANSYS Workbench in CFD context in Mechatronics simulation group. Since then, Rheinmetall Automotive simulation department was able to expand the usage to almost all CAE disciplines with numerous coupled software tools at various company sites. For coupling, all available optiSLang options are used: solver wizards from standard GUI[22] as well as own solutions like custom integrations and scripting. Within six years, the optiSLang usage grew from pilot project to broad usage at Rheinmetall Automotive. It is expected to increase further due to growing hybrid and electrical mobility segment, among other influences.

4.1 Application Example

Rheinmetall Automotive simulation department applies optiSLang i.e. in the context of controlling the impact of high thermal loads on engine parts. Those thermal loads affect various

[22] GUI = graphical user interface

products of division Mechatronics. Variants analyses inside optiSLang support the determination of operating limits, the detection of needs for improvement and the disclosure of optimization potential. Thus, optiSLang enables efficient part development based on profound system understanding. Those applications are related to sensitivity analyses calling CFD and FEA solver runs. While working those projects, some special challenges occurred. For example, it was ambitious to define suitable responses at first trial facing unknown output variation of the system. Unfortunately, first trial rarely was complete and fully useful with regard to objective and criteria definition for successive optimization tasks. In addition, resulting COP[23] level of first trial responses often had potential for improvement. Low COP level could occur in the context of FEA strain prediction caused by moving maxima, to give an example. Subsequent response definition without repetition of time-consuming DoE would help to overcome those challenges.

4.2 Subsequent Response Definition with Field-MOP

In order to realize subsequent response definition, Rheinmetall Automotive simulation department defined a corporate pilot project for software Statistics on Structures (SoS) with Dynardo. Figure 5 shows exemplarily the resulting workflow.

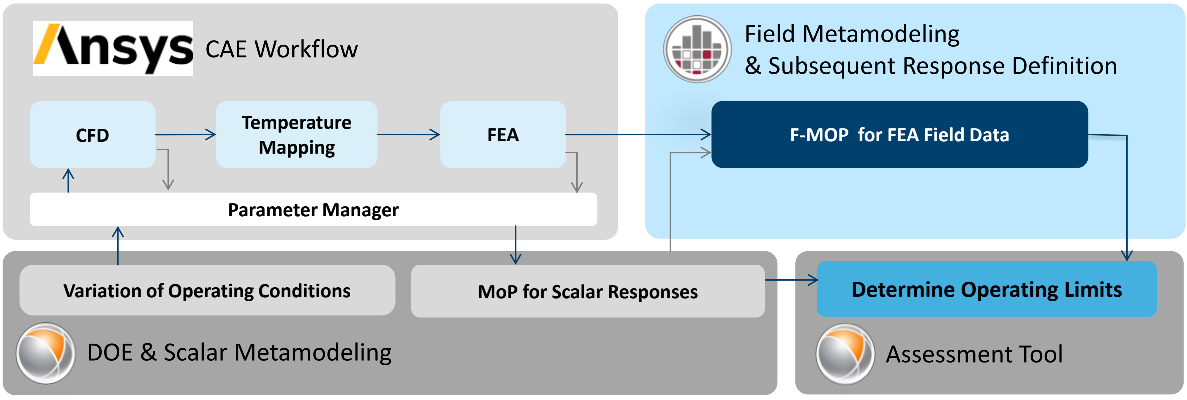

Figure 5: Example of Rheinmetall Automotive Workflow for subsequent Response Definition

Foundation of the workflow is a DoE setup using optiSLang. In case of determination of operating limits, operating conditions are varied. optiSLang is coupled to ANSYS Workbench which hosts the CAE workflow. It consists of CFD run, temperature mapping block and FEA calculation. From ANSYS workbench, optiSLang collects scalar responses. For fieldmetamodels (F-MOP) and subsequent response definition, software SoS is used. FEA field data export for each DoE design is required for calculation of fieldmetamodels. In addition, the needed information about input variation is provided by optiSLang. Finally, an assessment tool for determination of operating limits is realized in optiSLang. All metamodels are linked to the tool and enable real-time evaluation of arbitrary load cases for engine parts under thermal load. Building optiSLang components are MOP and Field-MOP solvers as well as ETK[24] node which

[23] COP = coefficient of prognosis
[24] ETK = extraction tool kit

collects the subsequently defined responses. It is obvious that such assessment tool fully benefits from optiSLang timesaving capabilities.

5 Summary & Next Steps

This paper provides an insight into optiSLang history at Rheinmetall Automotive simulation department. It depicts why Rheinmetall Automotive had to go into the direction of CAE variants analysis and how it started to raise optiSLang to be an established tool. Since Rheinmetall Automotive simulation department is convinced by the advantages performing CAE variants analysis, it is willing to share some of its experience in present article. The more people share and live the spirit of CAE variants analysis inside and outside the company the better for products and processes.

First section of this paper depicts the initial situation. Since Rheinmetall Automotive simulation department works as internal CAE service supplier, organizational context is explained. After that, paper depicts the motivation for simulation-driven design optimization including CAE-based variants analysis. Thereby, the project management principles and requirements handling are examined. Finally, a continuous simulation workflow is presented as part of Rheinmetall Automotive simulation department vision. This workflow enables early innovative design concepts and releases the power of profound system understanding.

Second section describes the first steps of Rheinmetall Automotive simulation department in the field of CAE variants analysis. One of those steps is the usage of mesh morphing approach as enabling technology. In addition, the close collaboration with Niederrhein University of Applied Science resulting in optiSLang pilot project and purchase of first license is in focus.

Third section depicts the optiSLang introduction challenges: project time lines, mindset of project decision makers, education of CAE engineers. It also shows the successful introduction strategy which consists of three pillars: flagship projects, PR-strategy and knowledge management.

Last section provides an insight into the transition from scalar metamodels to fieldmetamodels at Rheinmetall Automotive simulation department. This transition was necessary due to the need for subsequent response definition (after performing CAE-based DoE). Controlling the impact of high thermal loads on engine parts is given as application example for fieldmetamodeling.

Pushed by the idea of simulation-driven design optimization, the power of CAE variants analysis conquered Rheinmetall Automotive. Convinced by the benefits, Rheinmetall Automotive simulation department spent a lot of effort to introduce optiSLang in the company. It took six years, to raise optiSLang from pilot projects to broad usage at Rheinmetall Automotive. Medium-term topics are to further expand the international usage of optiSLang and SoS and to launch Rheinmetall Automotive optiSLang webinterface.

Since optiSlang story of Rheinmetall Automotive is individual, it is not possible to just copy and apply the introduction strategy to other companies or departments. But sharing the Rheinmetall Automotive experience will support defining optiSLang introduction strategies and the identification of introduction challenges.

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