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Adaptive Learner Progression and Support for At-Risk Engineering Students in Odel

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Abstract

Online Distance Electronic Learning (ODeL) engineering tuition often brings together students with widely differing levels of prior knowledge, preparedness, and self-directed learning capability. In such contexts, one-size-fits-all instructional approaches may fail to support at-risk students effectively, resulting in weak progression, low confidence, and poor academic performance. This paper proposes and evaluates an adaptive learner-support framework designed to enhance learner progression and autonomy in ODeL engineering contexts. The framework is anchored in diagnostic pre-assessment, which establishes baseline competency and enables the classification of students into differentiated performance groups. These groups are supported through staged, adaptive interventions, including scaffolding and laddering, adaptive learning pathways, digital game-based learning, and the gradual release of responsibility, supported by continuous feedback and monitoring. A mixed-methods comparative design was employed to evaluate the framework, integrating assessment data with observations, surveys, field notes, and documentary analysis. Results indicate that the intervention reduced the proportion of struggling students, increased the number of high-performing students, and improved overall learner performance by approximately 25%. Qualitative findings further suggest enhanced learner engagement, confidence, and development of self-directed learning capabilities. The study concludes that adaptive learner-support frameworks provide an effective and scalable approach for addressing learner variability in ODeL engineering education. By aligning diagnostic assessment, differentiated instruction, and iterative feedback, the framework contributes to improved learner autonomy, retention, and academic success in mixed-ability cohorts.

Keywords
Adaptive learner progression; at-risk engineering students; Online Distance Electronic Learning (ODeL); differentiated learner support.

1. Introduction
Engineering education plays a critical role in preparing graduates for technological innovation, industrial development, and complex problem solving. Higher education institutions are therefore under increasing pressure to ensure that engineering graduates possess not only disciplinary knowledge, but also the practical, transversal, and professional competencies required by contemporary industry and society (Boyle et al. 2022). This challenge is particularly acute in Online Distance Electronic Learning (ODeL) environments, where students are expected to learn more independently while navigating digital systems, asynchronous engagement, and reduced face-to-face support (Liu et al. 2021; Rotar 2022). Successful distance learning often assumes strong motivation, goal-directedness, self-regulation, and the ability to work both independently and collaboratively, yet these attributes vary considerably across student cohorts (Dos Santos 2020; Rotar 2022). This diversity is especially evident in ODeL engineering tuition, where students enter with different levels of prior knowledge, academic preparation, exposure to technical tools, and capacity for self-directed learning (El-Sabagh 2021; Rotar 2022). In such contexts, a one-size-fits-all approach is unlikely to meet learners' varied needs, readiness levels, and rates of progression. Adaptive and personalised e-learning approaches therefore offer a more suitable alternative, as they can improve engagement and learning outcomes by aligning instruction more closely with student needs (El-Sabagh 2021; Rotar 2022). Some literature suggests that

learner-centred and outcome-oriented approaches can improve educational effectiveness in engineering contexts. Results-driven and competency-based models emphasise measurable learning outcomes, relevance to industry, and the alignment of teaching strategies with the competencies learners are expected to demonstrate (Devies et al. 2022; Zhang, Cao & Cheng 2026).

Similarly, active, problem-based, and design-oriented approaches have been shown to strengthen student understanding and improve the application of knowledge to authentic and real-world problems more effectively than passive or purely content-driven forms of teaching. In engineering education specifically, hands-on instruction, design-oriented learning, and opportunities for progressively more complex problem solving are especially important because they help students move beyond memorisation toward practical competence, systems thinking, and adaptive reasoning (Pusca & Northwood 2018). Within ODeL, however, these pedagogical principles need to be supported by structured learner-support mechanisms that can respond practically to mixed-ability cohorts and differences in learner readiness. Adaptive learning, scaffolding, laddering, and gradual release of responsibility offer useful ways of differentiating instruction according to learner need, particularly in contexts where students do not begin with the same levels of prior knowledge, confidence, or capacity for self-directed learning. These approaches are especially relevant for students who begin with low comprehension or weak baseline performance because they allow learning tasks to be broken down into manageable stages while still enabling progression toward more complex and increasingly autonomous learning. In this regard, pre-assessment becomes an essential diagnostic tool because it enables the identification of learners' "as is" state, supports performance-based grouping, and provides a basis for designing support pathways that respond to actual learner need rather than assuming equal readiness across the class. In the present study, this logic is reflected in the grouping of students into performance bands and in the differentiated use of scaffolding, laddering, adaptive learning, and digital game-based learning to support progression and autonomy. This paper therefore shifts attention from curriculum design in general to the more specific issue of adaptive learner progression and support for at-risk engineering students in ODeL. It investigates how differentiated support pathways can be used to identify underprepared learners, strengthen their progression, and improve movement from dependence toward increasing autonomy. More specifically, the paper examines the role of diagnostic pre-assessment, performance-based grouping, and staged support strategies in improving learner outcomes in engineering tuition. In doing so, it contributes a differentiated learner-support model for ODeL engineering education that is responsive to learner variability and focused on progression, retention, performance improvement, and student autonomy.

2. Literature Review

2.1 Engineering Education, Graduate Competencies, and Industry Expectations

Recent literature increasingly frames engineering education around comprehensive competency development rather than the acquisition of isolated technical skills. Multiple studies argue that future-ready engineers require integrated competency frameworks that bring together technical, cognitive, social, and meta-competencies such as adaptability, ethical reasoning, collaboration, and lifelong learning (Fernando et al. 2025; Garcés et al. 2025). These frameworks respond to the growing complexity of engineering practice, where engineers are expected to operate in interdisciplinary, technology-intensive, and socially responsive environments. Holistic models such as the Spherical Competency Model conceptualise graduate competence as dynamic and interdependent rather than linear or hierarchical. In this model, technical competence is inseparable from human-centricity, creativity, adaptability, and systems thinking, all of which are essential for Industry 5.0 contexts (Fernando et al. 2025). Other competency frameworks emphasise sustainability, social responsibility, and ethical reasoning, explicitly aligning engineering curricula with the Sustainable Development Goals and broader societal imperatives(Garcés et al. 2025; Mangalore, Gamit & Kanchan 2025). These perspectives reinforce the idea that engineering education must support not only disciplinary mastery but also reflective judgment, resilience, and autonomy qualities that are particularly relevant in self-directed ODeL environments.

2.2 ODeL Contexts and Learner Variability in Engineering Education

The movement toward holistic competency development has been accompanied by a shift away from transmissive teaching models toward active and innovative pedagogies. Approaches such as project-based, problem-based, and challenge-based learning are widely recognised as effective in developing both technical and transversal competencies, including problem solving, teamwork, and communication (Leles et al. 2024; Naseer et al. 2025). These pedagogies encourage learners to engage with authentic, ill-structured problems and to integrate knowledge across domains rather than treating learning as the accumulation of discrete content units. The integration of digital technologies, artificial intelligence, and data-driven learning environments further extends the potential of these pedagogical approaches. Technology-enhanced and experiential learning models support flexible pacing, adaptive feedback, and interdisciplinary engagement, thereby strengthening students' preparedness for rapidly evolving professional contexts and lifelong learning (Tshikolu et al. 2025;). Frameworks such as EPIC (Engage, Practice, Integrate, Communicate) and other technology-supported pedagogical models illustrate how structured learning design can promote deep learning while still accommodating differences in readiness and progression (Ang & Domingo 2025). Within ODeL, however, the effectiveness of such innovations depends heavily on the presence of learner-support structures that help students navigate increasing autonomy.

2.3 At-Risk Students and Progression Challenges in Engineering

The concept of "at-risk" students in higher education is commonly associated with under preparedness, weak academic performance, delayed progression, or increased likelihood of attrition (York et al. 2015). In an engineering context, students may be considered at risk due to limited prior exposure to mathematics, physics, or technical problem-solving, alongside difficulties in adapting to abstract reasoning and high cognitive load (Case & Marshall 2009). Within ODeL, these risks are further heightened by reduced external structure and lower levels of direct academic and social integration (Bhowmik 2013). Literature argues that early identification and structured support are critical in improving outcomes for at-risk students (Jayaprakash et al. 2014; Tinto 2017). Without timely intervention, struggling learners may become increasingly disengaged, experience declining confidence, and ultimately withdraw from their studies. Effective support therefore requires more than remedial content; it necessitates carefully designed progression pathways that scaffold learning, reinforce foundational competencies, and gradually foster independence. In engineering education, where mastery depends on both conceptual understanding and procedural fluency, such pathways are especially important for supporting movement from dependence to autonomy.

2.4 Adaptive Learning, Differentiated Instruction, and Scaffolding

Adaptive learning approaches are grounded in the principle that instruction should respond dynamically to learner characteristics, performance, and progress (Rotar 2022). Rather than delivering identical content to all learners, adaptive systems and pedagogies adjust learning tasks, feedback, pacing, or support structures in line with demonstrated need. In engineering education, adaptive learning has been associated with improved engagement, better alignment between instruction and learner readiness, and more efficient use of learning time (El-Sabagh 2021). Scaffolding and laddering are closely related pedagogical strategies that support adaptive learning by structuring tasks from simpler to more complex forms (Hmelo-Silver et al. 2007). Scaffolding provides temporary support such as guided examples, prompts, or worked solutions that is gradually withdrawn as learners gain competence. Laddering, similarly, emphasises progression through incremental stages of difficulty, allowing learners to consolidate understanding before advancing. These approaches are particularly effective for students with weak baseline knowledge, as they reduce cognitive overload while maintaining alignment with higher-order learning outcomes (Sweller 2020). When applied systematically, scaffolding and laddering can promote confidence, persistence, and gradual development of self-directed learning skills.

2.5 Diagnostic Pre-Assessment and Performance-Based Grouping

Diagnostic pre-assessment plays a critical role in adaptive learner-support models by providing insight into learners' prior knowledge, misconceptions, and readiness levels before instruction begins (Nicol & MacFarlane-Dick 2006). In engineering education, pre-assessment can reveal gaps in prerequisite mathematical or conceptual understanding that would otherwise remain invisible until formal assessments are conducted. By establishing learners' "as is" state, educators can make informed decisions about pacing, differentiation, and the allocation of support resources. Performance-based grouping, derived from diagnostic data, enables instructors to provide targeted interventions without lowering overall academic standards (Sharma 2023). Rather than tracking students permanently, effective grouping remains flexible and responsive to learner progress, allowing movement between support levels as competence improves. In ODeL settings, such grouping can guide the differentiated use of learning materials, feedback intensity, and support mechanisms, ensuring that struggling students receive additional structure while more advanced learners are challenged appropriately. This approach aligns with equity-oriented pedagogies by responding to learner need while maintaining common learning outcomes.

2.6 Digital Game-Based Learning and Engagement in Engineering

Digital game-based learning (DGBL) has gained attention as a means of enhancing motivation, engagement, and persistence in STEM education (Plass, Homer & Kinzer 2015; Qian & Clark 2016). In an engineering context, game-based elements such as immediate feedback, progressive levels, and challenge-based tasks can support conceptual understanding while sustaining learner interest. Importantly, DGBL can be integrated into adaptive support models by aligning game mechanics with progression pathways and mastery thresholds rather than using games as stand-alone motivational tools. For at-risk learners, game-based environments may reduce anxiety associated with failure by framing learning as iterative and exploratory rather than punitive (Hamari et al. 2016). When designed to reinforce foundational concepts and procedural fluency, DGBL can complement scaffolding and laddering by providing repeated practice in an engaging format. In ODeL engineering tuition, where sustaining engagement over extended periods is a persistent challenge, the strategic use of DGBL can therefore contribute to both affective and cognitive dimensions of learner progression.

3. Suggested Adaptive Learner-Support Framework

3.1 Framework Design and Orientation

The proposed framework adopts a mixed-methods, data-informed design orientation to support adaptive learner progression in Online Distance Electronic Learning (ODeL) engineering contexts. The framework integrates quantitative performance monitoring with qualitative insights into learner engagement, behaviour, and autonomy development. This dual emphasis facilitates a holistic understanding of learner progression and enables evidence-based adaptation of instructional strategies. The framework is designed to be iterative and responsive, allowing continuous refinement through ongoing data collection, analysis, and feedback.

3.2 Contextual Applicability and Target Population

The framework is intended for use in ODeL engineering environments characterised by diverse and mixed-ability cohorts. Such contexts typically include learners with varying levels of:

- Prior academic preparation
- Technical proficiency
- Self-directed learning capacity

The framework assumes the presence of both traditionally prepared and at-risk learners and is specifically structured to support equitable progression across these groups. It is suited for integration within standard instructional processes, thereby ensuring authenticity and practical applicability within real teaching and learning environments.

3.3 Diagnostic Pre-Assessment and Learner Profiling

A central component of the framework is the use of diagnostic pre-assessment to establish baseline learner competency. This process evaluates:

- Foundational knowledge
- Conceptual understanding
- Problem-solving ability

Based on the diagnostic results, learners are categorised into dynamic performance-based profiles, which may include:

- Emerging learners (low baseline competency; at risk)
- Developing learners (moderate competency; requiring structured support)
- Proficient learners (higher competency; capable of increasing independence)

These profiles are not fixed; rather, they serve as initial indicators of readiness and are continuously updated based on learner progression.

3.4 Core Components of the Adaptive Support Framework

The framework operationalises learner support through a set of integrated and staged pedagogical strategies, each contributing to progression and autonomy.

3.4.1 Scaffolding and Laddering

Learning activities are organised in a progressive sequence, moving from foundational concepts toward increasingly complex engineering tasks.

- Early stages emphasise guided instruction, structured examples, and explicit feedback
- Subsequent stages reduce support as competence improves

This approach supports cognitive development while mitigating overload, particularly for at-risk learners.

3.4.2 Adaptive Learning Pathways

Instruction is differentiated based on learner profiles, enabling customised progression pathways.
Adaptation occurs in terms of:

- Task complexity
- Learning pace
- Feedback intensity

This ensures that learners engage with material at an appropriate level of challenge, promoting both competence development and sustained engagement.

3.4.3 Digital Game-Based Learning (DGBL)

Targeted integration of digital game-based learning enhances:

- Motivation and engagement
- Repetition and reinforcement of key concepts
- Immediate formative feedback

DGBL provides a low-risk, iterative learning environment that supports skill consolidation, particularly for learners requiring additional practice.

3.4.4 Gradual Release of Responsibility

The framework incorporates a structured transition from dependence to autonomy, consistent with learner-centred pedagogical approaches.

- Initial stages: high levels of lecturer guidance
- Intermediate stages: shared responsibility between lecturer and learner
- Advanced stages: learner independence and self-regulation

This progression supports the development of self-directed learning capabilities, which are critical in ODeL environments.

3.5 Feedback, Monitoring, and Iterative Adaptation

The framework emphasises continuous monitoring and feedback loops to inform instructional decisions and learner support.
Key data sources include:

- Assessment performance
- Learner interactions and participation
- Observations and reflective field notes
- Student feedback and perceptions

These inputs enable:

- Real-time identification of struggling learners
- Adjustment of support strategies
- Movement of learners between support levels

This iterative process ensures that the framework remains dynamic, responsive, and learner-centred.

3.6 Alignment with Learner Progression Outcomes

The framework is explicitly designed to influence three key outcomes:

- Performance improvement (measured through assessment data)
- Reduction in at-risk learners (movement across performance bands)
- Development of learner autonomy (observational and self-reported indicators)

By integrating diagnostic assessment, differentiated instruction, and continuous feedback, the framework provides a structured pathway for progression from dependence to independent, self-regulated learning.

3.7 Framework Contribution

This suggested framework extends existing approaches to engineering education in ODeL by:

- Bridging competency-based education and adaptive learner support
- Providing a practically implementable model for mixed-ability cohorts
- Linking diagnostic assessment directly to instructional differentiation
- Emphasising progression, retention, and learner autonomy

It offers a scalable and transferable model that can be adapted across engineering modules and similar ODeL contexts.

3.8 Conceptual Model of the Adaptive Learner-Support Framework

Figure 1 presents the conceptual structure of the adaptive learner-support framework underpinning this study. The framework illustrates the relationship between diagnostic pre-assessment, performance-based grouping, and the implementation of staged instructional interventions. These interventions including scaffolding, adaptive learning, digital game-based learning, and gradual release of responsibility are applied in a differentiated manner to support learner progression. The framework incorporates a continuous feedback and monitoring loop, enabling dynamic movement of learners between performance levels as competence improves. This cyclical design reflects the iterative nature of adaptive learning in ODeL contexts and provides a structured pathway from dependent to autonomous learning.

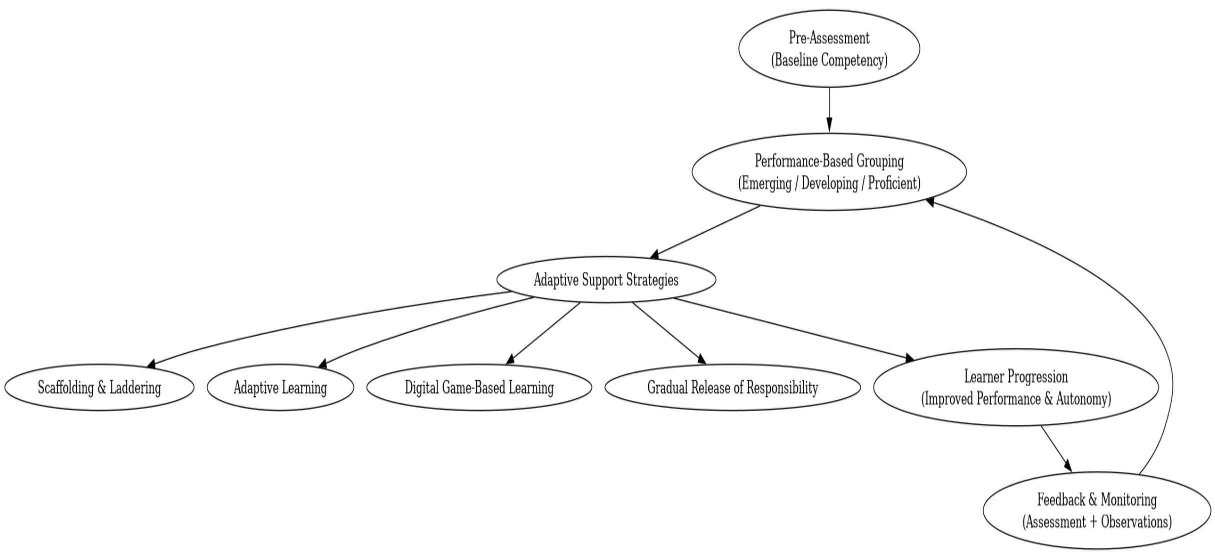

Figure 1. Adaptive learner-support framework

4. Results and Discussion

4.1 Baseline Learner Competency and Initial Grouping

The diagnostic pre-assessment provided a clear indication of variability in learner readiness at the outset of the module. Students were distributed across the three performance categories emerging, developing, and proficient confirming the presence of a mixed-ability cohort with a significant proportion of at-risk learners. The baseline data highlighted gaps in foundational knowledge and problem-solving ability among emerging learners, reinforcing the necessity of differentiated support. These findings align with the rationale for the adaptive framework, which assumes unequal readiness and emphasises targeted intervention rather than uniform instruction. Establishing this baseline was critical for tracking progression and evaluating the effectiveness of the subsequent interventions.

4.2 Impact of Adaptive Interventions on Learner Performance

Quantitative analysis of assessment data indicates a substantial improvement in learner performance following the implementation of the adaptive learner-support framework. Overall, many students demonstrated performance gains of approximately 25%, with notable shifts in the distribution of learners across performance categories. Specifically:

- The proportion of emerging (at-risk) learners decreased significantly over the duration of the intervention
- The number of developing learners increased initially, followed by progression into higher performance levels
- The proportion of proficient and excelling learners increased, indicating successful upward movement

These trends suggest that the staged interventions enabled learners to consolidate foundational knowledge before progressing to more complex tasks. The results support the effectiveness of scaffolding and laddering strategies, which structured learning in a way that made progression achievable without reducing academic standards. Furthermore, the differentiated support provided through adaptive learning pathways ensured that learners engaged with tasks at an appropriate level of challenge, contributing to improved outcomes across the cohort.

4.3 Learner Engagement and the Role of Digital Game-Based Learning

Qualitative data from observations, surveys, and field notes indicate that digital game-based learning (DGBL) contributed to increased learner engagement and sustained participation, particularly among students initially identified as at risk. Learners reported that the interactive and iterative nature of game-based activities:

- Encouraged repeated practice without fear of failure
- Provided immediate feedback that supported self-correction
- Enhanced motivation, particularly in mastering foundational concepts

These findings suggest that DGBL functioned as a complementary support mechanism, reinforcing learning through engagement and repetition. In the context of ODeL, where maintaining engagement is often a challenge, the inclusion of DGBL appears to have mitigated disengagement and supported continuous participation.

4.4 Development of Learner Autonomy through Gradual Release

Evidence from survey responses and observational data indicates a progressive increase in learner autonomy over the course of the intervention. Initially, many learners relied heavily on structured guidance and explicit instruction. However, as support was gradually reduced through the gradual release of responsibility, learners demonstrated:

- Increased confidence in independent problem-solving
- Greater willingness to engage with complex tasks
- Improved ability to regulate their own learning processes

This progression reflects the effectiveness of the framework in facilitating a transition from dependent to self-directed learning. The findings support the view that autonomy in ODeL should be developed through structured support rather than assumed, particularly for students with limited prior experience of independent learning.

4.5 Iterative Feedback and Movement Between Performance Groups

The continuous feedback and monitoring mechanisms embedded in the framework enabled dynamic movement of learners across performance groups. Assessment data and observations indicate that:

- Learners initially classified as emerging were able to progress into developing and, in some cases, proficient categories
- Learner movement was not linear, with some students requiring additional support cycles before progressing
- Ongoing feedback allowed timely identification of learning difficulties and adjustment of support strategies

This iterative process underscores the importance of adaptive and responsive instruction in managing learner variability. Rather than fixed grouping, the framework supported a fluid progression model, where learners could move between levels based on demonstrated competence.

4.6 Integration of Findings and Implications for ODeL Engineering Education

The integration of quantitative and qualitative findings provides strong evidence for the effectiveness of the adaptive learner-support framework. The observed improvements in performance, reduction in at-risk learners, and increased learner autonomy collectively demonstrate that structured, data-informed support can significantly enhance progression in ODeL engineering contexts. The results also highlight the importance of aligning diagnostic assessment, differentiated instruction, and continuous feedback within a coherent framework. The combination of scaffolding, adaptive learning, DGBL, and gradual release created a multi-layered support system that addressed both cognitive and affective dimensions of learning. Importantly, the findings suggest that learner variability should be viewed not as a barrier, but as a design condition that requires adaptive instructional responses. By providing differentiated pathways and enabling progression at varying rates, the framework supports both at-risk learners and higher-performing students without compromising academic outcomes.

5. Conclusion

This study proposed and evaluated an adaptive learner-support framework designed to address learner variability in ODeL engineering education. The findings demonstrate that a structured approach combining diagnostic pre-assessment, differentiated support strategies, and iterative feedback mechanisms can significantly improve learner progression. The observed shift in performance distribution particularly the reduction in at-risk learners and the improvement in overall performance indicates that adaptive interventions can enhance both competence and confidence among students. The framework further supports the development of learner autonomy, enabling a gradual transition from dependence on instructional guidance to increased self-directed learning. This is particularly important in ODeL contexts, where independent learning is a critical requirement for success. Overall, the study contributes a scalable and transferable model that integrates adaptive pedagogy with competency-based progression. The framework offers a practical solution for supporting mixed-ability cohorts in engineering education and has the potential to improve retention, engagement, and academic success in similar contexts.

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