Learning Analytics-Driven Student Monitoring: Design and Evaluation of a Real-Time Feedback Toolkit

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DOI: https://dx.doi.org/10.47772/IJRISS.2026.100600135

Received: 27 May 2026; Accepted: 01 June 2026; Published: 19 June 2026

ABSTRACT

This study explores the user experience of the Traffic Signals Toolkit, a teaching innovation designed for Data and Information Visualization, an undergraduate elective course. Using the intuitive red–yellow–green metaphor, the toolkit supports both student self-regulation and instructor monitoring by signaling levels of understanding in real time. Data were collected from 75 students across two semesters through entrance surveys, an interactive exercise, and exit surveys. Results show significant gains in conceptual understanding, technical skills, independence, and error-handling, with survey comparisons confirming improvements across all five measured dimensions. Toolkit signals further demonstrated a clear progression from confusion to mastery. Students valued its clarity and reflective prompts, while instructors benefited from actionable insights. The findings suggest that this scalable, low-barrier approach has broader potential for enhancing pedagogy in data-intensive learning contexts.

Keywords: Learning tool, real-time feedback, information visualization, learning analytics.

INTRODUCTION

Higher education continues to face persistent challenges in ensuring that students acquire not only theoretical knowledge but also practical, higher-order skills. In data-driven disciplines, such as information systems and data visualization, these challenges are magnified by the complexity of course content, diversity of student backgrounds, and the need for continuous engagement in hands-on learning. Traditional methods of monitoring progress such as quizzes, assignments, or verbal check-ins often fail to capture real-time difficulties that students experience during practice. Consequently, instructors may overlook learners who silently struggle, and students themselves may lack adequate mechanisms for reflecting on their own progress. The growing field of learning analytics offers a potential solution. Defined as the "measurement, collection, analysis, and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs" (Siemens, 2013, p. 1380), learning analytics enables a more systematic, evidence-based approach to teaching. By transforming raw learning data into actionable insights, educators can intervene at critical points, while students can use feedback to adjust strategies and strengthen self-regulation.

In particular, the IMS563 – Data and Information Visualisation course at Universiti Teknologi MARA (UiTM) provides an ideal context for exploring this potential. As an elective course, IMS563 attracts students from diverse academic backgrounds with varying levels of programming proficiency and motivation. It also demands mastery of complex concepts, including the modeling and visualization of high-dimensional datasets. The course allocates 12 hours to hands-on activities, requiring learners to apply advanced visualization techniques, interpret results, and present findings. Monitoring such varied and intensive learning experiences is difficult without technological support. In response to these challenges, the Traffic Signals Toolkit was developed as an instructional innovation grounded in learning analytics. The toolkit applies the universal metaphor of traffic signals to simplify complex feedback processes: a red light signals a lack of understanding, yellow denotes partial comprehension requiring guidance, and a green indicates mastery. By integrating this coding system into a digital platform, the toolkit enables students to self-assess and communicate their learning state in real time. Simultaneously, instructors gain access to aggregated visualizations of class progress, allowing them to identify struggling learners and adapt instruction accordingly.

In essence, this paper examines the user experience of the Traffic Signals Toolkit within the IMS563 course. Specifically, it addresses two objectives: (i) to evaluate the effectiveness of the toolkit in monitoring students' progress and (ii) to explore student perceptions and experiences of using the toolkit for learning and feedback. By triangulating system-generated data with survey responses, the study provides insights into both the objective performance outcomes and the subjective experiences of students. The significance of this study lies in its contribution to the evidence base for analytics-driven teaching innovations. While dashboards and performance-tracking tools have gained popularity, few studies focus on simple, intuitive mechanisms that promote both real-time feedback and learner autonomy. The Traffic Signals Toolkit addresses this gap by aligning analytics with user-centred design principles, emphasizing clarity, accessibility, and immediate utility for both students and instructors.

The remainder of this paper is structured as follows. Section 2 reviews the literature on learning analytics, feedback, and self-regulated learning. Section 3 describes the methodology of the study, including the course context, participants, and data collection instruments. Section 4 presents the findings, while Section 5 discusses the results in relation to existing research. Sections 6 and 7 outline practical implications and directions for future work, respectively. The paper concludes by summarizing the contributions of the study to both practice and research in higher education.

LITERATURE REVIEW

Learning Analytics in Higher Education

The rise of learning analytics (LA) reflects a growing need for evidence-based decision-making in higher education. Siemens (2013) defines LA as the collection, measurement, analysis, and reporting of data about learners and their contexts to improve teaching and learning. Ferguson (2012) emphasizes that LA serves as both a diagnostic and predictive tool, allowing educators to identify students at risk, personalize instruction, and evaluate pedagogical effectiveness. By integrating digital traces of learning such as survey responses, system interactions, and performance data LA transforms fragmented classroom experiences into actionable insights. Several studies demonstrate the positive impact of LA on student outcomes. Gašević, Dawson, and Siemens (2015) argue that LA can foster not only academic achievement but also self-regulated learning by providing students with feedback loops that encourage reflection and adjustment. Ifenthaler and Yau (2020) highlight its role in promoting study success by detecting challenges early and enabling tailored support. Despite these advantages, challenges remain in ensuring that analytics tools are intuitive, accessible, and supportive of both learners and instructors.

Feedback and Self-Regulated Learning

Feedback plays a pivotal role in shaping student learning. According to Hattie and Timperley (2007), effective feedback addresses three key questions: Where am I going? How am I going? Where to next? For feedback to be impactful, it must be timely, specific, and actionable. However, in traditional classrooms, providing individualized, real-time feedback is often impractical due to large class sizes, diverse learner needs, and time constraints. Self-regulated learning (SRL) frameworks emphasize the importance of learner autonomy, reflection, and strategic adjustment (Zimmerman, 2002). Feedback mechanisms embedded within SRL processes allow students to monitor their progress, evaluate performance against goals, and adapt learning behaviors. LA tools, when designed with SRL in mind, can bridge the gap between external instructional support and internal learner regulation (Viberg et al., 2018). The Traffic Signals Toolkit builds on these principles by encouraging students to self-assess their comprehension using a simple red–yellow–green system. This design not only empowers learners to reflect on their state of understanding but also provides instructors with immediate insights into where interventions are required.

Pedagogical Challenges in Data Visualization Courses

Data and Information Visualization courses present unique instructional challenges. Ware (2019) highlights the cognitive load associated with interpreting complex, high-dimensional data. Students must integrate technical skills (e.g., programming, tool use) with higher-order thinking skills (e.g., analysis, interpretation, communication). The hands-on nature of visualization tasks demands extended practice and iterative refinement, making continuous monitoring essential. At UiTM, IMS563 is an elective course that attracts students with varied levels of motivation, prior knowledge, and programming expertise. This diversity often results in uneven learning trajectories. Some students excel quickly, while others require significant scaffolding. Instructors face difficulties in identifying struggling learners during practical sessions, as students may hesitate to seek help or overestimate their comprehension. Without systematic support, these disparities can lead to frustration, disengagement, or gaps in mastery.

Teaching Innovations with Analytics and Dashboards

In response to such challenges, numerous teaching innovations have leveraged LA to support learning. Dashboards, for instance, provide visual summaries of student performance, enabling instructors to identify trends and intervene (Verbert et al., 2013). Adaptive learning systems use data-driven algorithms to personalize content delivery and pacing (Papamitsiou & Economides, 2014). Gamified feedback mechanisms, such as badges and progress bars, have also been explored to enhance motivation and engagement (Dichev & Dicheva, 2017). While these approaches are valuable, they often involve complex technologies that may be overwhelming for both instructors and students. The Traffic Signals Toolkit addresses this gap by offering a minimalist, intuitive approach. By using universally understood traffic signal colors, the toolkit simplifies performance monitoring without compromising on depth of insight. Its integration within Microsoft Forms further ensures accessibility and scalability, requiring minimal technical expertise. Although the literature confirms the effectiveness of LA and feedback mechanisms, relatively few studies examine user experiences of simple, color-coded interventions in higher education. Most prior work emphasizes predictive models or complex dashboards, overlooking the potential of low-barrier tools that promote active learner participation. Moreover, research on data visualization pedagogy often focuses on curricular content rather than feedback mechanisms.

This study contributes to filling these gaps by:

- Evaluating the effectiveness of the Traffic Signals Toolkit in monitoring progress.
- Exploring student perceptions and experiences with the toolkit.
- Demonstrating how a simple, intuitive system can enhance both teaching and learning in a technically demanding course.

By foregrounding user experience, this research highlights the importance of designing analytics tools that are not only functional but also engaging and empowering for learners.

METHODOLOGY

Research Context

This study was situated in IMS563 – Data and Information Visualization, an undergraduate elective course offered at Universiti Teknologi MARA (UiTM), Puncak Perdana Campus. The course is designed to introduce students to advanced concepts in data analysis and visualization, emphasizing both theoretical knowledge and practical application. Students are required to work with complex, high-dimensional datasets and employ various

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

visualization techniques while also developing higher-order thinking skills such as analysis, interpretation, and problem-solving.

The elective nature of the course means that participants come from diverse academic backgrounds. Some students possess strong programming experience and an aptitude for data-driven problem-solving, while others have limited prior exposure to such tasks. This variation often creates disparities in learning outcomes, with some students excelling quickly while others struggle to keep up. Instructors face challenges in identifying and addressing these difficulties in real time, as traditional assessment methods rarely provide immediate feedback. The Traffic Signals Toolkit was therefore introduced as an innovation to support both learners and instructors by enabling systematic monitoring of progress and fostering self-reflection.

Participants

The participants in this study consisted of two consecutive cohorts of undergraduate students enrolled in IMS563. In Semester 2 of the 2024/2025 academic session (coded 20244), thirty-five students participated, while in Semester 1 of the 2025/2026 session (coded 20252), the number increased to forty students. In total, seventy-five students engaged with the Traffic Signals Toolkit as part of their coursework. Participation was fully integrated into the learning activities of the course, ensuring that all students completed the surveys and exercises, with no attrition across the two cohorts.

Instruments and Intervention

The instructional intervention was developed and administered using Microsoft Forms, chosen for its accessibility and user-friendliness. The module consisted of three interconnected components: an entrance survey, a hands-on exercise incorporating the Traffic Signals Toolkit, and an exit survey. The entrance survey was administered before the exercise to establish baseline data on students' prior knowledge, technical skills, and confidence. It contained five items assessing students' understanding of the topic, ability to use data visualization tools, independence in completing tasks, competence in presenting data, and ability to detect and correct errors.

The exercise module formed the core of the intervention. Students were tasked with applying data visualization concepts to a provided dataset while simultaneously using the Traffic Signals Toolkit to self-assess their level of comprehension. The toolkit's traffic light metaphor allowed students to choose one of three signals: red if they did not understand and needed full assistance, yellow if they partially understood and required hints, and green if they had achieved mastery. This design encouraged self-reflection while enabling instructors to view aggregated signals on a dashboard, providing a clear overview of student progress and areas requiring attention. The exit survey was administered at the conclusion of the exercise. It mirrored the entrance survey in both structure and content, allowing for comparisons of self-assessed competence before and after the intervention. In addition, the exit survey provided space for open-ended reflections, enabling students to share their perceptions of the toolkit and its impact on their learning.

Data Collection

Data collection was timed to coincide with Topic 4: Configuring Data Environment, a stage in the course where students had acquired sufficient foundational knowledge to engage meaningfully with hands-on visualization tasks. This ensured that the intervention was introduced at a point when students were prepared to apply their learning but still likely to encounter difficulties that warranted monitoring and support. Three types of data were collected. First, survey responses provided quantitative measures of changes in students' understanding, skills, and confidence. Second, the exercise outputs demonstrated students' ability to apply theoretical concepts in practice. Finally, the toolkit signals (red, yellow, green) captured real-time self-assessments of comprehension during the exercise, offering a dynamic view of how students' learning evolved.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

Data Analysis

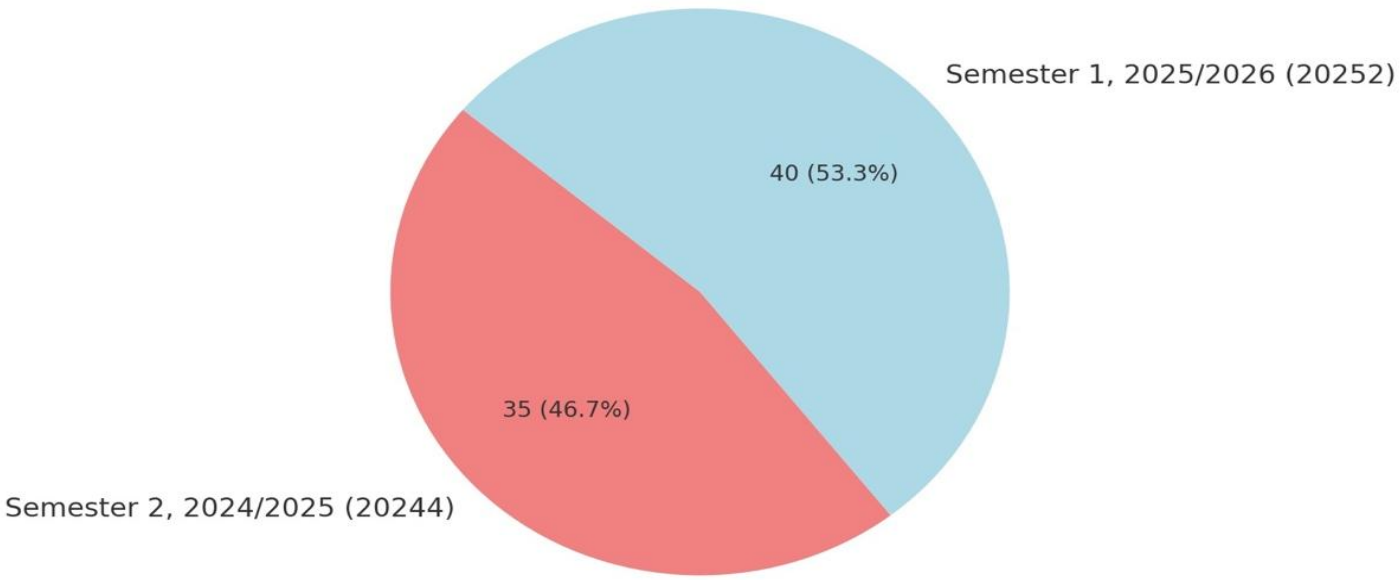
The analysis of the data was guided by the study's two research objectives. To evaluate the effectiveness of the Traffic Signals Toolkit in monitoring students' progress, descriptive statistics were used to analyze the distribution of red, yellow, and green responses across the exercise. Trends in these signals were examined to determine whether students moved from requiring assistance toward mastery. To explore student perceptions and experiences, entrance and exit survey results were compared to identify shifts in self-assessed competence, while qualitative reflections from the exit survey were thematically analyzed to highlight recurring patterns in students' experiences. By combining logged data and survey data, the study ensured that the evaluation of the Traffic Signals Toolkit was not limited to measurable outcomes but also encompassed students' lived experiences, thereby providing a holistic understanding of its impact on teaching and learning.

STUDY FINDINGS

Participant Information

A total of seventy-five undergraduate students participated in the study, representing two consecutive cohorts of the IMS563 – Data and Information Visualization course at UiTM. The first cohort, drawn from Semester 2 of the 2024/2025 academic year (coded 20244), comprised thirty-five students, while the second cohort, from Semester 1 of the 2025/2026 academic year (coded 20252), included forty students (refer Figure 1). All participants engaged fully with the intervention, completing the entrance survey, participating in the hands-on exercise incorporating the Traffic Signals Toolkit, and responding to the exit survey. The absence of attrition ensured a complete dataset across both cohorts, enhancing the reliability of the findings.

Figure 1. The participant distribution across cohort (n=75)

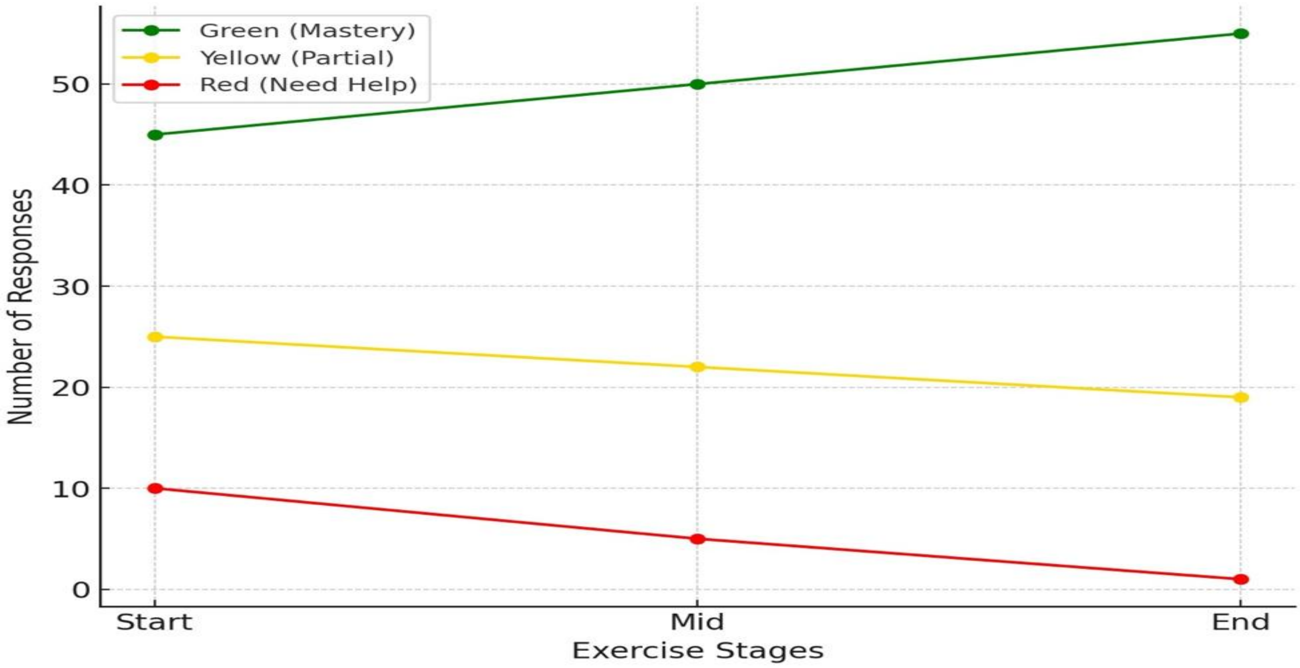


Effectiveness of the Toolkit

The first research objective was to assess the effectiveness of the Traffic Signals Toolkit in monitoring students' progress during the exercise. Analysis of toolkit signals revealed a consistent upward trajectory in comprehension levels across the cohort. At the outset, a considerable number of students signaled partial understanding (yellow, n = 25) or indicated the need for full assistance (red, n = 10), while 45 students reported mastery (green). As the activity progressed, green signals increased to 55, yellow responses declined to 19, and red signals diminished to a single case. This distribution, illustrated in Figure 2, demonstrates a clear progression from initial uncertainty toward competence and mastery.

The steady shift in traffic signal responses underscores the toolkit's diagnostic value in both identifying and addressing learning needs in real time. Clusters of yellow and red responses early in the activity indicated points of difficulty, which enabled instructors to provide timely interventions. The subsequent rise in green signals not only reflects the impact of instructional support but also suggests that students became more confident and autonomous as they advanced. This trend highlights how the toolkit effectively fostered self-regulation among learners while simultaneously equipping instructors with actionable insights into classroom dynamics.

Figure 2. The distribution of red, yellow, and green signals recorded at the start, middle, and end of the exercise while students progress via the Traffic Signals Toolkit



Student Perceptions and Experiences

Meanwhile, the second research objective examined student perceptions of their learning experience through comparisons of entrance and exit survey data. Across all five survey items, substantial improvements were observed. The results are presented in Table 1, which compares entrance and exit scores across the five learning dimensions.

The entrance survey results reveal that students began the course with moderate confidence in their knowledge and skills, with all items averaging between 2.77 and 3.27 on a five-point scale. This suggests that students recognized the technical demands of the course and were uncertain of their ability to work independently or resolve errors without assistance. The lowest entrance score was recorded for Q5 (error-handling), at 2.77, highlighting a significant gap in self-reliance at the outset. In contrast, the exit survey results show marked improvements across all items, with mean scores ranging between 4.15 and 4.43.

Table 1. Entrance and exit survey results for student perceptions of learning.

Survey Item	Entrance Mean	Exit Mean	Mean Difference
Q1: I am able to understand this topic adequately.	3.27	4.43	+1.16
Q2: I am able to use data visualization tools with basic numerical skills.	3.23	4.41	+1.18
Q3: I am able to do the hands-on activities independently.	3.04	4.29	+1.25
Q4: I am able to present data with appropriate visual representations.	3.09	4.28	+1.19

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Q5: I am able to detect and resolve errors without any assistance.	2.77	4.15	+1.38
Q1: I am able to understand this topic adequately.	3.27	4.43	+1.16

These results indicate that, by the end of the intervention, students felt confident in their understanding of the content, capable of applying tools effectively, and able to work independently with reduced reliance on instructor support. Notably, the greatest improvement was again in error-handling (Q5), which rose by 1.38 points, followed closely by independence (Q3), which improved by 1.25 points. These substantial gains suggest that the Traffic Signals Toolkit not only enhanced content mastery but also built resilience and self-regulation skills. Overall, the data demonstrate that the toolkit contributed to a significant positive shift in both confidence and competence, supporting the argument that simple, intuitive self-assessment tools can yield profound learning benefits.

User Experience Insights

Qualitative feedback from students complemented the quantitative findings. Many described the Traffic Signals Toolkit as intuitive and easy to use, noting that the color-coded system made it simple to reflect on their level of understanding. Several students remarked that the signals encouraged them to pause and think critically about their progress rather than rushing through tasks. The universal metaphor of traffic lights reduced cognitive load, allowing learners to focus on content rather than tool mechanics.

From the instructors' perspective, the aggregated dashboard view offered valuable insights. Clusters of yellow or red signals highlighted common difficulties, prompting targeted explanations, while increasing green signals reassured instructors of collective progress. This bidirectional value providing students with reflective opportunities and instructors with actionable data represents one of the toolkit's strongest contributions to the learning environment.

DISCUSSIONS

The findings provide strong evidence of the Traffic Signals Toolkit's effectiveness in monitoring student progress and promoting self-regulated learning. The steady increase in green signals, alongside the decline in red and yellow, illustrates a shift from dependency toward mastery. This progression reflects Zimmerman's (2002) model of self-regulation, where learners transition from guided practice to independent competence. By requiring students to signal their comprehension, the toolkit encouraged metacognitive reflection, enabling learners to evaluate their understanding and seek support when needed. For instructors, the aggregated dashboard offered a timely overview of difficulties, aligning with Verbert et al.'s (2013) view that dashboards enhance instructional responsiveness. Unlike complex analytics systems, however, the simplicity of the traffic-light metaphor reduced cognitive load while maintaining diagnostic utility.

Beyond comprehension, the toolkit contributed to student confidence and competence. Survey data showed consistent improvement across all five dimensions, with the largest gains in independence and error-handling. This finding is particularly significant for programming and visualization contexts, where troubleshooting is a key determinant of success. By providing a non-threatening means of acknowledging uncertainty, the toolkit empowered students to confront rather than avoid errors, thereby fostering resilience. These outcomes resonate with Hattie and Timperley's (2007) framework on feedback as both informative and motivational and support Gašević, Dawson, and Siemens' (2015) argument that learning analytics deepen engagement by prompting reflection on challenges and strategies.

Equally important, the study underscores the value of user experience in learning analytics. While prior research has emphasized predictive modeling and outcomes (Papamitsiou & Economides, 2014), this study highlights the affective dimension of student engagement. Feedback from participants suggested that the toolkit's intuitive design and low-stakes signaling fostered a sense of agency and psychological safety. Such usability considerations are critical, as Ifenthaler and Yau (2020) warn that overly complex tools may alienate learners

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

rather than support them. By contrast, the Traffic Signals Toolkit demonstrates how minimalist interventions can achieve substantial pedagogical impact precisely through their accessibility and ease of use.

Finally, the toolkit can be situated within broader pedagogical innovations such as gamified progress indicators (Dichev & Dicheva, 2017) and adaptive feedback systems. Its distinctive strength lies in scalability and accessibility, as its implementation within Microsoft Forms requires minimal technical expertise while remaining adaptable across disciplines. This practicality makes it especially valuable in courses that integrate technical skill development with higher-order problem-solving, such as data visualization. In such contexts, the toolkit not only facilitates real-time self-assessment but also equips instructors with insights that might otherwise remain hidden, reinforcing its potential as a versatile tool for enhancing teaching and learning.

Implications

The results of this study highlight several important implications for teaching practice. For instructors, the Traffic Signals Toolkit provides a simple yet effective means of monitoring student progress in real time. The red–yellow–green signals offer a clear overview of comprehension across the cohort, enabling instructors to identify difficulties early and provide targeted support. Unlike more complex analytics platforms, the toolkit's intuitive design reduces preparation time and cognitive load, making it feasible for courses with diverse cohorts and limited resources.

For students, the toolkit supports the development of metacognitive skills by requiring them to reflect on their own understanding and signal their level of confidence. This process not only strengthened immediate comprehension but also fostered independence, resilience, and error-handling competencies that are crucial for success in data-intensive and problem-solving courses. The results suggest that the toolkit can play a significant role in cultivating self-regulated learners, who are better equipped to manage uncertainty and adapt their strategies.

At a broader level, the Traffic Signals Toolkit offers a model for curriculum designers and institutions seeking scalable, low-cost approaches to integrating learning analytics. Because it can be implemented within existing tools such as Microsoft Forms, the intervention requires minimal technical expertise and can be easily adapted to different disciplines. Its potential for supporting accreditation efforts, enhancing teaching quality, and addressing diverse learner needs positions it as a practical pedagogical innovation with relevance beyond the immediate course context.

LIMITATIONS AND RECOMMENDATIONS

Despite its promising results, this study has several limitations that must be acknowledged. First, the analysis relied heavily on self-reported survey data, which may be influenced by social desirability bias or students' subjective perceptions. Although triangulated with toolkit signals, future research should incorporate performance-based measures or longitudinal tracking to strengthen validity. Second, the study was conducted within a single course at one institution, which limits the generalizability of findings. Broader application across disciplines, programs, and institutional contexts would provide stronger evidence of scalability. Finally, while the toolkit's simplicity was a notable strength, it may not capture more complex learning attributes such as creativity, collaboration, or critical thinking, which are equally important in higher education.

Based on these limitations, several recommendations are proposed. Future studies should employ mixed-methods designs, combining toolkit signals with objective performance metrics and qualitative data to provide richer insights. Expanding implementation across multiple courses and disciplines would allow researchers to test adaptability and scalability in varied contexts. Integration with learning management systems could also enhance functionality, linking real-time signals with broader analytics such as assignment performance and course engagement. Additionally, exploring extensions of the toolkit to capture more nuanced skills while retaining its user-friendly design could further increase its pedagogical value. Collectively, these directions would not only refine the toolkit but also contribute to the growing evidence base for learning analytics innovations that balance simplicity, usability, and impact.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

FUTURE WORK AND CONCLUSION

The results of this study demonstrate the promise of the Traffic Signals Toolkit while also highlighting directions for future research. Expanding its use beyond the IMS563 course would provide insights into its adaptability across disciplines such as programming, engineering, and applied sciences, where skill-based learning demands both real-time monitoring and reflective practice. Investigating the toolkit in these varied contexts would test its scalability and generalizability.

The survey instrument demonstrates content validity and construct validity through triangulation with toolkit signals and qualitative feedback. However, the paper does not provide reliability coefficients (e.g., Cronbach's alpha). Therefore, while the instrument appears appropriate for measuring perceived learning gains, the evidence for its reliability and validity remains preliminary and should be strengthened in future research.

Future studies should also adopt longitudinal designs to assess whether the gains in confidence, independence, and error-handling persist across entire semesters or multiple courses. Such work would clarify whether the toolkit not only improves immediate comprehension but also contributes to long-term academic performance, retention, and engagement. Linking toolkit use to broader learning outcomes would strengthen its evidence base.

Integration with learning management systems (LMS) offers another avenue for development. By connecting toolkit signals to data such as assignments, participation, and grades, educators could gain a more holistic view of student progress. However, maintaining the toolkit's simplicity is critical, as its intuitive design was central to its positive reception. Future research could also extend the toolkit to capture more nuanced skills, including creativity, collaboration, and critical thinking, while preserving ease of use.

In conclusion, this study provides evidence that the Traffic Signals Toolkit enhances student learning and empowers instructors through real-time insights. The steady increase in mastery signals, survey improvements across multiple dimensions, and positive user feedback affirm its dual value as both a reflective tool for learners and a diagnostic tool for educators. Importantly, the toolkit illustrates that pedagogical innovations need not be complex or resource-intensive to achieve meaningful impact. With further refinement and broader adoption, it holds strong potential to contribute to evidence-based teaching and learning across higher education.

ACKNOWLEDGEMENT

The authors would like to express their sincere appreciation to all students enrolled in the Data and Information Visualization course across the two semesters who participated in this study. Their valuable cooperation, engagement, and feedback greatly contributed to the successful completion of this research. The authors also extend their gratitude to the Faculty of Information Science for its continuous support and facilitation throughout the study.

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