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The Reflectometer: A Novel Tool for Capturing the Quality of Students' Learning Experiences in Health Care Education, and Beyond

Richard Fjellaksel[1,2]*, Tim Dassler[2] and Tove Irene Dahl[2]

[1]UiT The Arctic University of Norway, department of health and care sciences
[2] UiT The Arctic Univiersity of Norway, department of Psychology, Center for Avalanche Research and Education

*Corresponding author's e-mail address: Richard.fjellaksel@uit.no

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Abstract

This paper introduces the Reflectometer, a novel tool designed to systematically capture and assess the quality and intensity of students' learning experiences. Grounded in theories of experiential and transformative learning, the Reflectometer enables the identification of Key Learning Moments (KLMs), including both Dislocatory Moments (DMs) and Key Memorable Events (KMEs), and supports the analysis of reflective processes such as double-loop learning. The tool combines visual and qualitative data to provide a multidimensional account of when and how learning occurs. We tested the Reflectometer in two contrasting educational contexts – radiography education and avalanche safety training – demonstrating its adaptability, utility, and capacity to reveal both expected and unexpected learning dynamics. The Reflectometer not only offers students a structured medium for reflection but also provides educators with valuable insights into students' learning experiences, thereby enabling two-way learning. Our findings suggest that the Reflectometer provides a promising method for stimulating reflective practice and assessing the impact of pedagogical strategies across diverse learning environments.

Introduction

Reflective practice plays a central role in bridging experiential and theoretical knowledge with practical application (1,2), especially in fields like health care and outdoor education (3-7). These environments require learners to act under conditions of uncertainty, urgency, and high potential consequences. Yet, the capacity to learn through reflection is difficult to cultivate and remains an educational challenge for students and teachers alike (8,9). It requires extra effort (often a barrier) from both teachers and students. Although tools for facilitating reflection – such as reflective journals, diaries, smartphone apps, and learning moment platforms – do exist and are excellent for capturing learning experiences (10–14), many of the tools used may not be specifically designed to prompt learning moments that promote lasting, deeper understanding. This underscores the need to thoughtfully design inviting contexts for reflective practice and tools that can be used to facilitate learning from practice (15). Notably, though, there are no assessment tools for this kind of reflective practice that have to date been identified and tested across multiple contexts (15).

Motivated by a desire to better assess and understand learning experiences that stimulate reflection and double-loop learning, we developed the Reflectometer. Our objective was to design a tool capable of capturing the intensity and nature of learning moments while being practical and adaptable across diverse educational settings. The Reflectometer underwent a three-stage development process: design, testing, and evaluation.

We tested and evaluated the Reflectometer in two different cases and learning environments: radiography education and avalanche safety training. The purpose of this paper is to present the design process, examine how the tool functions across contexts, and evaluate its potential to (1) capture the intensity and quality of learning experiences, and (2) foster reflection and improve teaching and learning.

This is closely tied to the following research questions:

1. Can the Reflectometer capture learning experiences, including their intensity and the associated qualitative dimensions such as actions, thoughts, and feelings?
2. Can it help identify learning experiences, such as Dislocatory Learning Moments (DMs) and Key Memorable Events (KMEs), and reveal whether reflection was stimulated by these moments?
3. Can the Reflectometer enhance understanding and learning for both students and teachers?

Materials and Methods

This section outlines the three stages of the Reflectometer's development: designing the tool, testing it in two educational cases, and analyzing the resulting data. Here, we present an overview of the methods, with a more detailed description below.

Designing the Reflectometer

Purpose and Rationale

The Reflectometer was developed to systematically capture moments when learners experience significant learning, particularly those that stimulate reflection, insight, and deep understanding. Traditional reflective tools such as journals or learning diaries often lack the structure to pinpoint specific learning events, visualize their intensity or enable assessment of the impact of learning experiences (15). The Reflectometer addresses this gap by combining visual representation with information on the quality of the learning experience, enabling a richer and more precise documentation and assessment of learning processes. It is especially suited for contexts such as professional health care education, or outdoor education, where individuals must learn to make decisions under uncertainty and reflect on their evolving understanding before, during, and after instructional experiences.

Design and Implementation

The initial prototype, called the *Dis-locator (Figure 1)*, was inspired by the Feelometer (16,17), which maps emotional intensity during specific activities using a numeric scale.

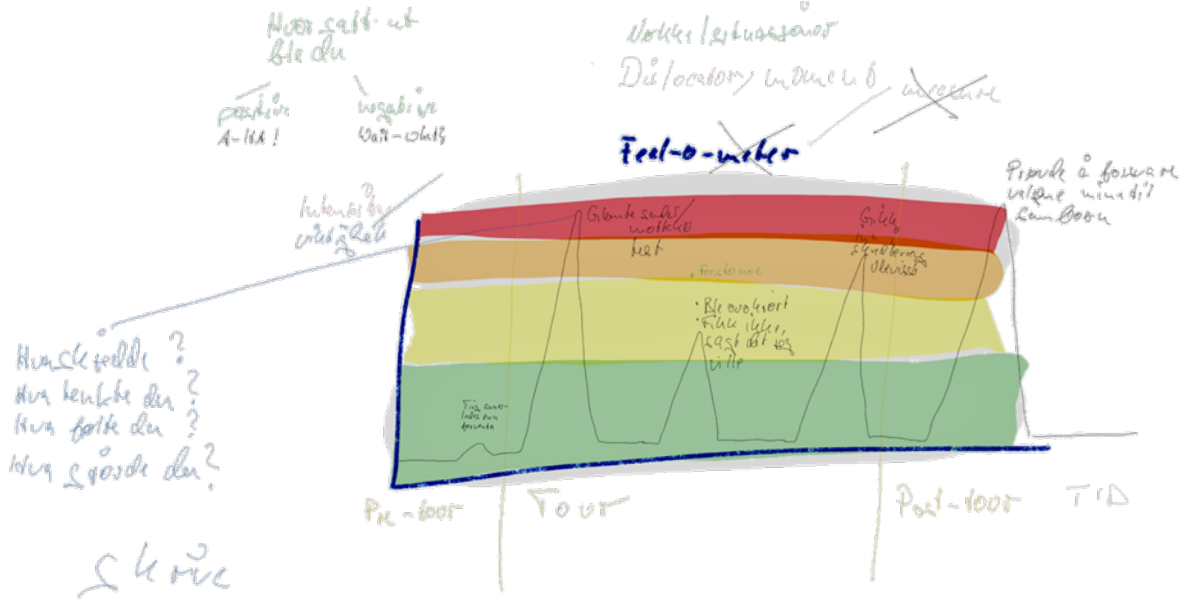

Figure 1. Sketch of the Dis-locator: an early prototype of the Reflectometer inspired by the Feelometer, showing learning intensity across time with a color-coded scale.

The Dis-locator was designed to identify "dislocatory moments" – disruptions in learners' assumptions or expectations. However, its name and reliance on color-coded zones (green to red) proved problematic due to negative associations and accessibility concerns related to color perception.

These limitations led to the development of a revised tool: the Reflectometer (Figure 2). It retains the time-based structure and intensity axis of the prototype but replaces color with a simplified vertical scale ranging from low to high. Students mark the intensity of their learning experiences on this graph, segmented along the x-axis into "before," "during," and "after" a learning session.

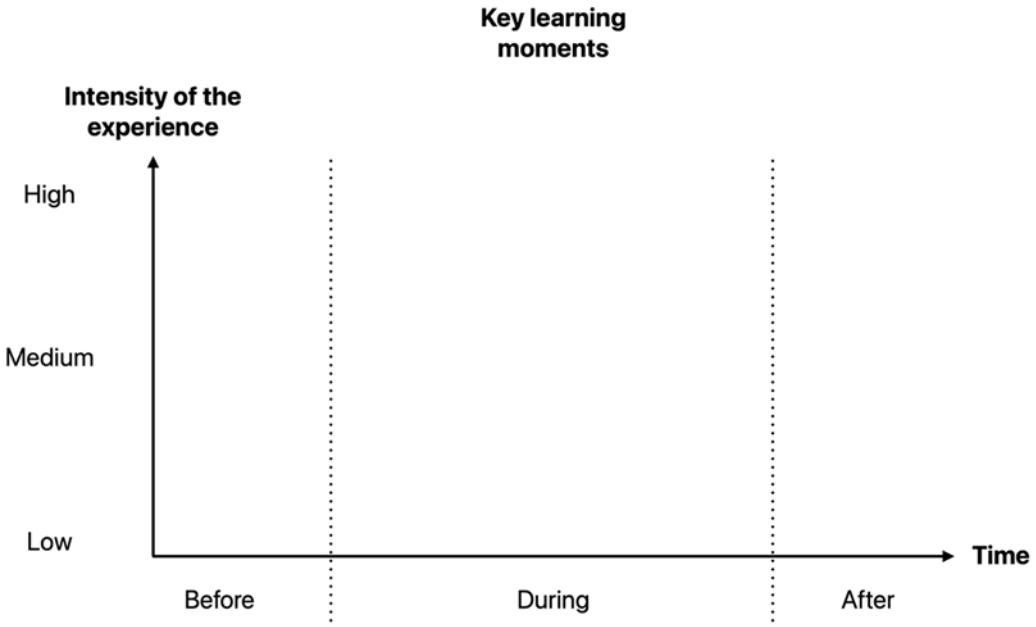

Figure 2. The Reflectometer template with a simplified vertical intensity scale (low to high) and a horizontal timeline divided into "before," "during," and "after" the learning session. Alongside the graph, students respond to guiding prompts: What happened? What were you thinking and feeling? What did you do? Were there any consequences? This combination of visual and narrative data could offer a more comprehensive understanding of learning dynamics.

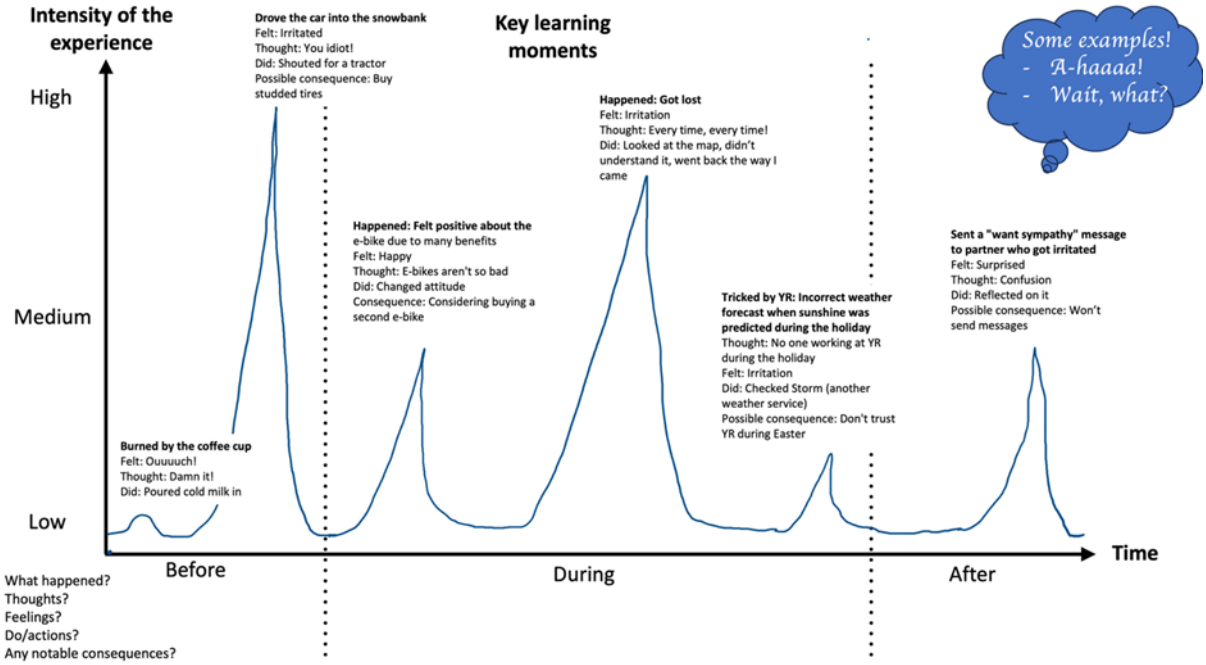

Figure 3. Example of a completed Reflectometer, illustrating how a student ideally documented key learning moments alongside brief narrative reflections. This example was provided for the students during the learning session.

Theoretical and Conceptual Foundations

The Reflectometer is grounded in experiential and transformative learning theories. Kolb's model emphasizes the learning cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation (18). Mezirow adds the importance of critical reflection and perspective transformation, often triggered by disorienting dilemmas or moments of dislocation (19).

To operationalize these theories, the Reflectometer was designed to capture what we termed Key Learning Moments (KLMs) – learning moments that are experienced as emotionally and cognitively significant by individuals. Two important subcategories are:

- ***Dislocatory Moments (DMs):*** Disruptive and often uncomfortable events that challenge existing beliefs, concepts or underlying assumptions, potentially triggering double-loop learning (20-23).
- ***Key Memorable Events (KMEs):*** Positive and affirming moments such as clarity, mastery, or insight, which reinforce confidence and engagement (24).

Reflection is central to both types. The tool facilitates *reflection-on-action* (21), prompting learners to revisit and analyze their experiences after the fact. In doing so, the Reflectometer supports the identification and assessment of double-loop learning – where learners not only adapt their actions but also reassess the underlying assumptions guiding them (20).

Capturing Learning Experiences

Figure 4 illustrates the types of learning experiences during a learning session (L) that can be reported in reflectometers both by students (S) based on their own experiences and by their teachers (T) based on their own observations of their students' learning. In the term "reflectometer zone", the area marked in gray, the learning experiences that students (S), teachers (T), or both students and teachers (S and T) are aware of, recall, and choose to report in a reflectometer become the reflectometer content. Such content is noted, likely because the experience is significant or meaningful for them (24). Meanwhile, the Learning Session circle that is not shaded gray represents any aspects of the learning session that does not register in students' reported learning experiences (i.e., things that they are either unaware of or choose not to report). The unshaded part of the student and teacher circles represent any other aspects of their concurrent experiences that are unrelated to the learning session (e.g., other things they may have on their mind).

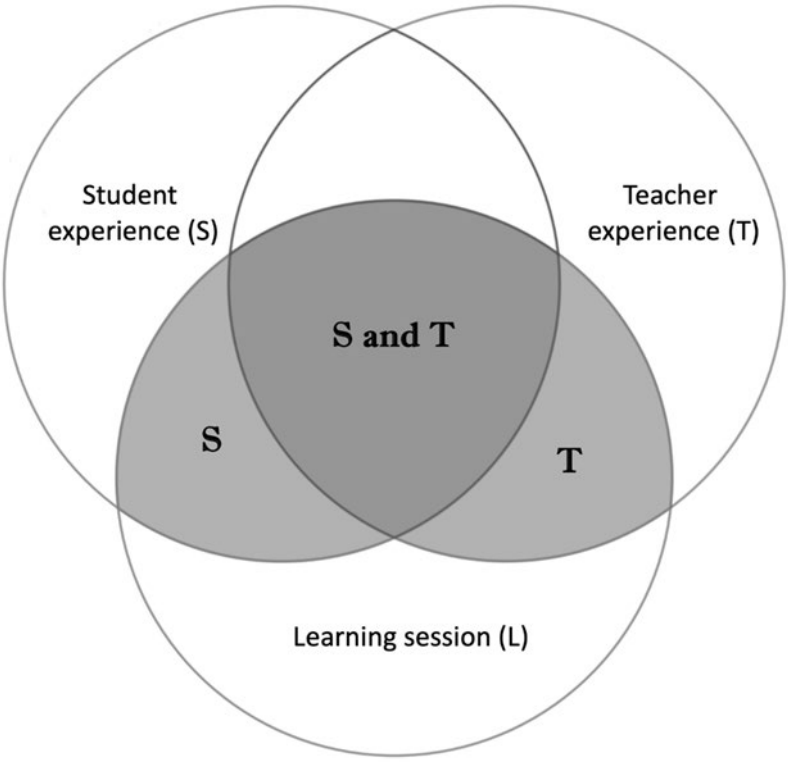

Figure 4. The Reflectometer Zone: a conceptual Venn diagram showing how students (S), teachers (T), or both (S and T) report overlapping or distinct learning experiences from the same session.

In theory, we reasoned, the Reflectometer should allow teachers to gain access to student learning experiences and insights that would otherwise remain hidden. This, in turn, can facilitate a basic form of two-way learning. By becoming aware of when and how students learn – and what challenges or breakthroughs they experience – teachers are better equipped to understand students' learning processes – including the impact of their teaching approaches on students' learning – and adjust their teaching strategies in real time. Here, we define two-way learning as a mutual process enabling teachers to learn from their students.

We also hoped that the tool would help distinguish between reported learning intensity and actual learning impact. While some students may report high intense moments without engaging in reflection, others may describe subtle yet transformative insights with lasting effects on their thinking and behavior.

In summary, the Reflectometer was designed as a structured, theoretically grounded, and user-friendly method for capturing and assessing learning experiences. By combining visual timelines with narrative reflections, the tool should enable a nuanced understanding of both the emotional and cognitive dimensions of meaningful learning experiences and their influence on learning. In this way providing its users with a unique lens through which to observe and analyze the richness and complexity of learning as it unfolds and assess its impact.

Testing the Reflectometer in Two Cases

We explored and tested the use of the Reflectometer in two distinct educational contexts: radiography education and avalanche training. Each setting involved different student groups and required tailored approaches to data collection and analysis. Below, we describe the students, procedures, context for and analysis of both cases.

Description of The Two Cases

Case 1: Radiography Education

Second-year bachelor's students in radiography underwent two skills training sessions in CT. They were divided into groups of three or four for each learning session. They received an introduction before each learning session and a summary after each learning session. The skills training sessions were structured so that during part 1, students follow a procedure/description of what they must do regarding technical parameters running the CT. They receive guidance along the way. Part 2 involved tasks and questions about image quality and machine parameters, following a procedure/description without guidance.

Case 2: Avalanche Training

Students participated in an explorative avalanche course that lasted over a whole ski-season (January to May 2023); 6 modules were covered in 11 days over 5 months. A learning session often consisted of a day on the mountain. The main goal was to prepare students to apply what they learned when going on their own trips.

Participants

Participants in this study came from two different course groups and are divided into students and teachers (Table 1).

Table 1. Overview of participants

	CT skill training 1	CT Skill training 2	Avalanche course
Students	17 (14 female and 3 male, 20-40 years old)	18 (15 female and 3 male, 20-40 years old)	10 (2 female and 8 male, 25-68 years old)
Teachers	3 (1 female and 2 males, 1-5 years experience)	4 (male, 1-5 years experience)	2 (males, > 5 years experience)

During the autumn 2023 radiography students were asked to participate in the study. They were provided with detailed information about the study, and their participation was entirely voluntary. The participants were from the radiography program at a medium-sized university in Norway (see Table 1). Each session was facilitated by one supervising teacher per group (three or four students), with some teachers overseeing multiple groups. There were two different skills training sessions with a CT machine (part one and part two), each lasting two hours per group.

The second case, the avalanche course, consisted of ten students and two teachers that took part in an avalanche training course in autumn 2023 in North Norway, Table 1. Students came to the course with a basic knowledge of alpine outdoor activities and winter backcountry travel.

Procedure – How did Participants fill out the Reflectometer?
In both cases, participants were introduced to the Reflectometer through a 30-minute orientation session. During this session, participants received detailed instructions on how to fill out the tool, including an example (see Figure 3) and they were given the opportunity to ask questions.
Students were asked to draw a graph where peaks represented the intensity of individual learning moments. These peaks could correspond to both positive insights and challenging or disruptive experiences. The x-axis denoted the timeline of the learning event (divided into "before," "during," and "after" the session), while the y-axis captured the perceived intensity of the learning moment.
The teachers of the course also filled out the reflectometer, but they were asked to draw and describe moments when they expected learning for the students to happen.

For each identified peak, participants were required to respond to a set of guiding questions, describing what occurred, their thoughts and feelings during the moment, any actions they took, and any consequences resulting from the experience.

The teachers and students in the CT machine skills training course were asked to complete the Reflectometer during the training sessions and again after each follow-up seminar, typically held a few days later. The students and the teachers in the avalanche course were asked to complete reflectometers after each day of instruction, ideally within 24 hours.

Explorative Analysis
After having explored how to use the reflectometer with the avalanche course participants, we additionally gathered Reflectometer data from radiography students and teachers. The collected data included intensity peak graphs and qualitative descriptions of reported learning moments. When analyzing the Reflectometers, we did two analyses; one where we merged and compared the learning intensity graphs from the radiography students and teachers, and one where we analyzed the reported learning moments in depth.

Merging and Comparing the Learning Intensity Graphs (Case 1)
In our initial analysis, we took all the student and teacher graphs and manually put them into one single composite Reflectometer to compare when students reported learning moments and when teachers expected learning to happen. In this analysis we compared student and teacher peaks and valleys. While student peaks meant that students experienced, remembered and reported learning moments or lack thereof (valleys), teacher peaks were indicative of where they expected students to learn. Comparing student and teacher graphs enabled us to see whether there was overlap between when teachers expected learning to happen and when students had a learning experience as they defined them.

Analyzing Types of Learning Moments - Looking for Signs of Double-Loop Learning (Case 1 and Case 2)
Reflectometer data from the avalanche training students (Case 2) was not suitable for comparative graph analysis, as done with the radiography students. This was due to several factors: the timing of "before" and "after" reflections varied widely between students; the group often split into smaller sub-groups with different learning experiences; and submissions included a mix of filed out Reflectometer templates, hand-drawn graphs, and Word documents, resulting in inconsistent formats. Consequently, the data were not amenable to direct comparison across individuals.

However, together with data from Case 1, it was well suited for a qualitative analysis of the descriptions of the reported peaks on the graph, specifically looking for four criteria to determine whether they could be counted as Key Learning Moments. The criteria that distinguished Key Learning Moments from other forms of intense experiences were that a KLM had to be reported as (1) intense (a peak on the timeline), (2) dislocatory or revelatory in some way, with (3) some kind of thought, feeling or action associated with it, and (4) an indication of a change in understanding, thinking, feeling and/or doing. KLMs where further analyzed to determine if they met the definition of a Dislocatory Moment (DM) – to be identified as such they had to satisfy the additional criteria of being experienced as uncomfortable and disruptive – or a Key Memorable Event – which was associated with a positive learning experience.

Additionally, we did an in-depth analysis looking for indications of double-loop learning in the data, particularly instances where students reflected on their actions and questioned underlying assumptions.

Ethics

One of the major ethical challenges to address when using the Reflectometer is that the teacher does not have control over the kind of information students provide. Students may choose to share personal information, not intended for the public. Thus, the use of the Reflectometer and the data collected should adhere to the highest ethical standards, ensuring anonymity and user data security. We treated data as red data (highest sensitivity).

All data were therefore anonymized and stored securely on a pre-approved university server. The study received approval from the Norwegian Centre for Research Data (SIKT, formerly NSD 733888) and ethical clearance from the institutional review board at the Department of Psychology at UiT The Arctic University of Norway, ensuring participants' anonymity and adherence to legal and ethical standards.

Results

In this section, we present the findings from both use cases. Figure 5 shows an example of the data generated by the Reflectometer. We begin with the comparative graph analysis from Case 1 (radiography education). We then turn to the results from the analysis of types of learning moments and signs for double-loop learning for both Case 1 and Case 2 (avalanche training).

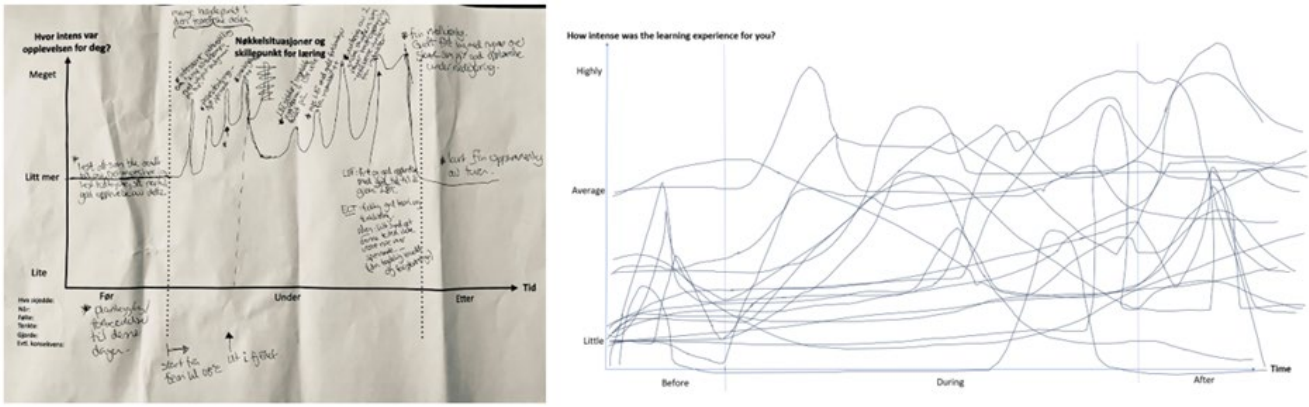

Figure 5. Left: Example from an individual reflectometer completed during avalanche training, showing several high-intensity Key Learning Moments (KLMs) with accompanying narrative descriptions. Right: Aggregated intensity graph from 18 radiography students' reflectometer reports during part 2 of the CT skill training.

Comparing Intensity Graphs (Case 1)

Comparing the teacher (expected learning) and student graphs (reported learning).
When we manually combined all Reflectometer graphs from the radiography students, distinct peaks – indicating reported learning moments – and valleys – where no learning was reported – became evident (see Figure 6a-b)

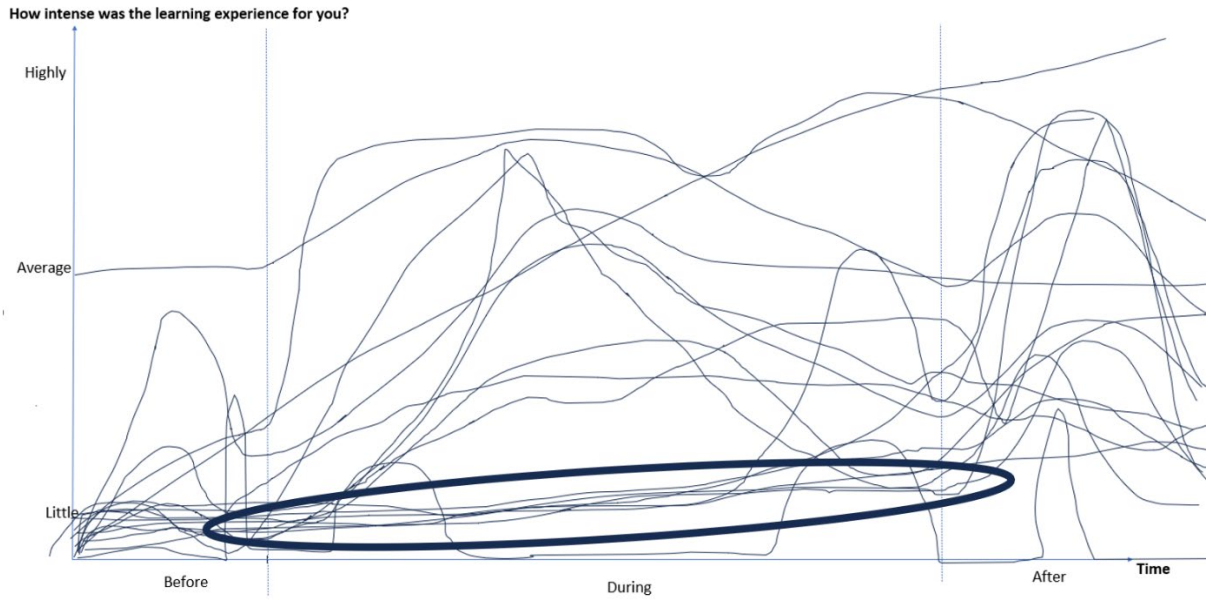

Figure 6a. Combined reflectometer reports from radiography students (n=17) for CT Skill training session 1 (of 2). Peaks mark reported Key Learning Moments, valleys mark lack of experienced learning moments. The thick black oval shows lack of learning moments during the training session for six students.

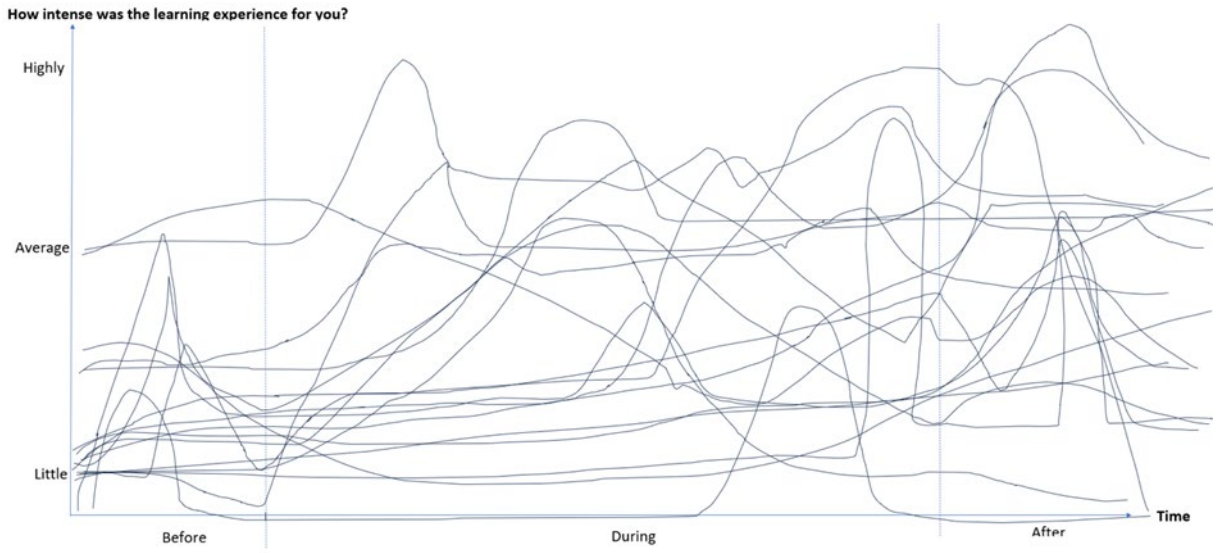

Figure 6b. Combined reflectometer reports from radiography students (n=18) for CT Skill training session 2 (of 2).

Figure 6a and 6b display the reported peaks (intense learning experiences) and valleys (no learning experience), showing that there is a lot of variation in the intensity as well as when different individuals experience learning during a session. Note that for the comparative graph analysis we did not do an in-depth analysis for the reported learning moments (peaks on the graph) and whether they qualified as Key Learning Moments, including their sub-

categories, as defined by our (the researchers') criteria. This means that peaks on the graph here represent what participants counted as Key Learning Moments, without an analysis if the peaks represented learning or other intense experiences. Students report a somewhat even spread of learning moments both before during and after the training session part 2 – with the highest intensity during and after the session (see Figure 6b).

When comparing teacher graphs with students' we could identify where there was a match between expected learning and experienced learning as reported by the students. Figure 7 below, where we compared two isolated student Reflectometers with one teacher Reflectometer from the CT skills training session part 1, exemplifies this finding.

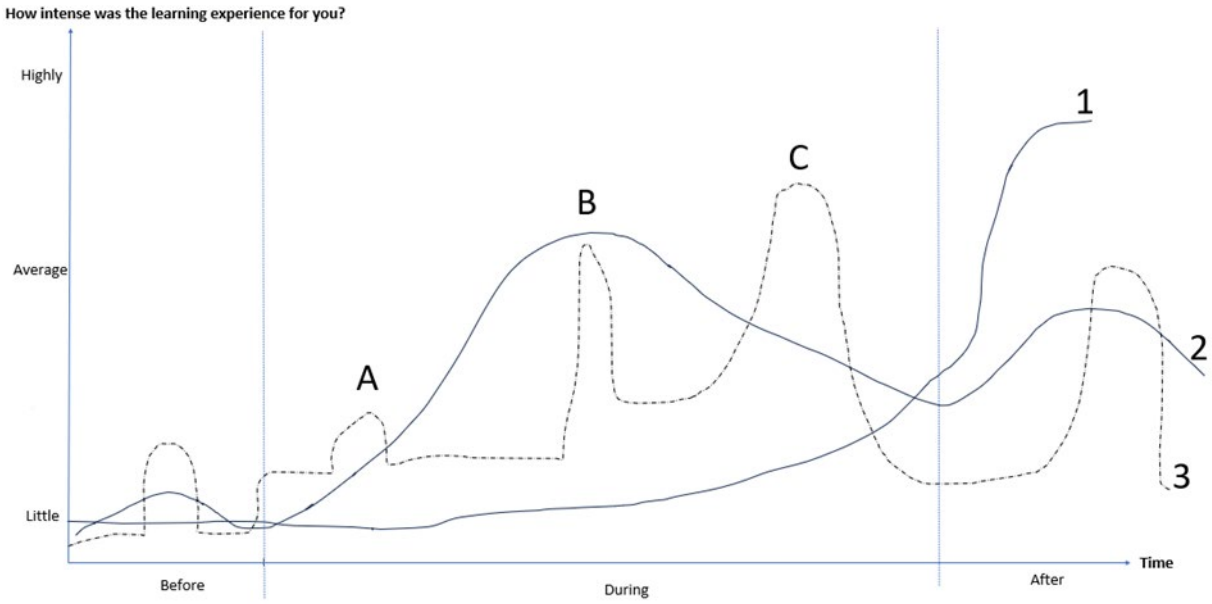

Figure 7. Example of intense learning moments (peaks) reported during CT Skills Training Session Part 1 by students (dark lines, 1 and 2) and the teacher (dotted line, 3).

In Figure 7, points A, B, and C represent the learning moments the teacher expected students to have. None of these are aligned with the learning moments reported by the student in graph 1, and only one (learning moment B) matched a reported moment in graph 2 during the training session. Interestingly, greater alignment was observed in the learning moments reported before and after the session, suggesting a mismatch during the session but convergence outside it.

This discrepancy was reflected in the experiences of several students who reported low levels of learning during Part 1 of the training session. As shown in Figure 6a, teachers' expectations are partly met by eleven students having relatively intense learning experiences during the session. Nevertheless, six students reported almost no experienced learning during the session (highlighted by the thick black oval), with only minor improvement toward the end. This suggests a substantial gap between instructional design and the students' perceived learning during the core of the session.

Discrepancies during the training sessions were not the only mismatches we discovered when comparing students' and teachers' graphs. Figure 8 shows the graphs drawn by the four teachers from the CT skills training part 2 in one composite Reflectometer, indicating when teachers expected students to experience key learning moments. It shows that while two teachers expect students to have medium to average intensity learning moments, the other two expect students to have average to high intensity learning moments. Note especially how teachers expect no learning to happen before and after the session.

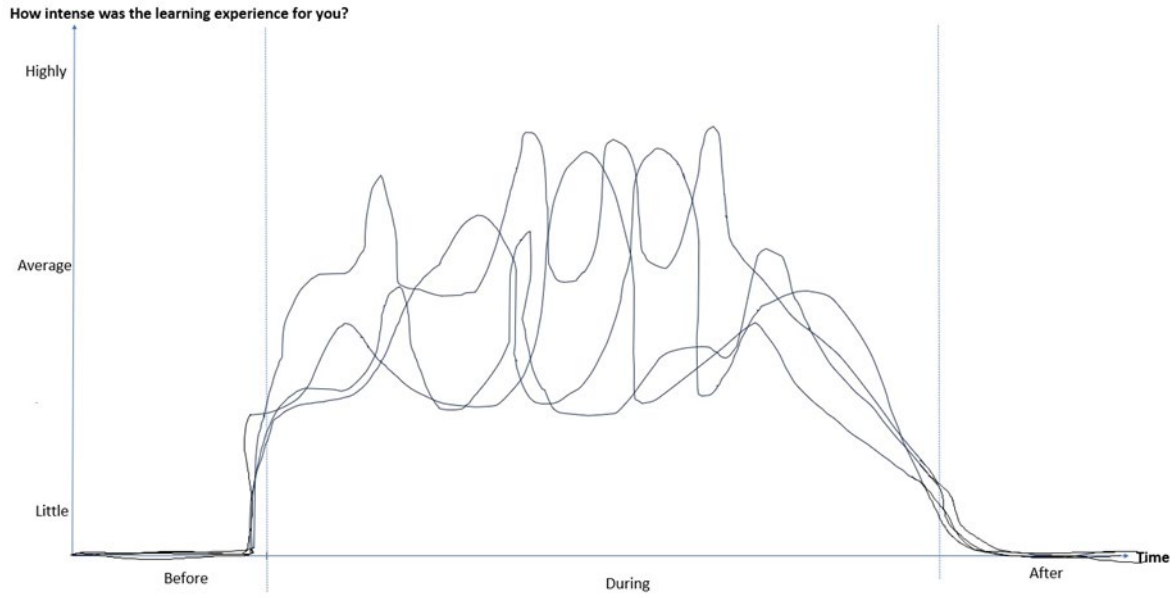

Figure 8. Data from teachers for the CT machine skills training session part 2.

3.2 Identification of Types of Learning Moments and Signs of Double-loop Learning (Case 1 and Case 2)

Case 1: Radiography Skills Training – Identifying Key Learning Moments

We also analyzed the qualitative descriptions provided by students and teachers alongside the graphs to identify the types of learning moments reported and to assess whether learning – as defined by our criteria – had occurred. This in-depth analysis focused on identifying changes in participants' thinking, feeling, understanding, or actions, and whether these experiences had any influence on intended future behavior.

Not all reported intense moments are really learning moments. We found that the Reflectometer effectively distinguishes between emotionally intense experiences – such as anticipatory reactions like "This will be good" – and intense learning experiences, such as those associated with Key Learning Moments (KLMs). Consider the following example reported by a radiography student during CT skill training part 1:

What happened: "Repeated how to use the CT machine"

Thoughts: "Need to practice more on it"

Feelings: "I miss practicing"

Do/actions: "Changed parameters and took many scans"

Any notable consequences: "I improved on it"

This reported moment could be identified as a Key Learning Moment, because it satisfied all the necessary criteria. "Changed parameter and took many scans" is a clear reported change in behavior which was stimulated by the change in thinking (insight) that the student "Needs[s] to practice more on [the CT machine]" and the associated "I miss practicing" indicating a feeling of longing or yearning. The student even reported a self-assessment: "I improved on [the CT machine]". In this case the insight and associated feeling prompted an intention to change in the future, showing that the qualitative Reflectometer data enabled us to distinguish between intense experiences and Key Learning Moments.

Case 2: Avalanche Training – Identifying Dislocatory Moments and Key Memorable Events

The findings from the radiography case were corroborated by the qualitative analysis of Reflectometer reports from the avalanche training participants. Here too, we were able to assess whether reported moments qualified as Key Learning Moments (KLMs), indicating that learning had occurred. Additionally, we could further distinguish between Dislocatory Moments (DMs) – marked by discomfort or disruption – and more positive experiences, such as Key Memorable Events (KMEs), often associated with clarity or a sense of mastery. Consider the two examples in Table 2.

Table 2. Empirical Examples of Types of Learning Moments from Participant Reflectometer Reports

Questions from Reflectometer	Empirical example of a KME	Empirical example of a DM
What happened:	"Instructor performed a very simple snow test using their pole."	"Avalanche scenario involving two people in close proximity. After probing on the same slope, further to the north."
Thoughts:	"That you can quickly gather useful information about the snow conditions along the way, without needing to make a longer stop to dig"	"This is going fine… this is going less fine… this is not going well…"
Feelings:	"Enthusiasm"	"Fuckshit."

Do/actions:	"Was not careful enough with the fine search using the probe before we started digging."
Any notable consequences:	"We ended up digging a much larger area than necessary and learned that the signal/marker doesn't just point downward, but also sideways – meaning the person can be located to the side of the pit you've dug."

By examining the reported emotions and thoughts associated with the two learning moments above, we can clearly distinguish between a Key Memorable Event (KME), characterized by positive thoughts and the feeling of "Enthusiasm", and a Dislocatory Moment (DM), marked by discomfort, self-doubt, and sudden insight into one's own shortcomings. The latter is reflected in the progression of thoughts ("…this is not going so well…") and the intense emotional reaction encapsulated in the expletive "Fuckshit," indicating panic, resignation, and a moment of cognitive disruption.

Identifying Signs of Double-Loop Learning

However, the Reflectometer enabled us to capture more than just the type of Key Learning Moment – whether it was a Key Memorable Experience (KME) or a Dislocatory Learning Moment (DM). It also allowed us to identify and assess instances where double-loop learning was stimulated – that is, when participants not only responded to a problem but also critically examined and revised the underlying assumptions guiding their actions.

Table 3. Empirical Examples of Double-loop Learning from Case 2

Questions from Reflectometer	**Empirical example 1**	**Empirical example 2**
What happened:	"Literature"	"Review of Systematic Snow cover Analysis, snow types, and various technical profiling/sampling processes, along with reflection on the rule of thumb. The entire session took place indoors."

Thoughts:	"I should have read it earlier"	"Realizing how little I know (or knew) about snow and avalanche assessment."
Feelings:	"Realized I want to learn"	"Frustration, overwhelmed"
Do/actions:	"I read through all literature, made me aware. I also prepared questions for the next day."	"Changed attitude."
Any notable consequences:	"More prepared and I learned more during the following day"	"Became motivated to learn more and had the opportunity to reflect on my own thoughts."
Assessment of double-loop learning		
Signs of double-loop learning (analysis)	Realizing that to optimize learning outcomes, it is essential to engage with relevant literature in advance of a learning session – prompting reflection on one's own motivation and responsibility for learning.	Reflecting on and realizing that effectively addressing the problem required a fundamental change in attitude – an insight that, in turn, influenced and strengthened the participant's motivation to engage in learning.

In both examples, the participants move beyond merely reacting to the problem – as is typical with single-loop learning; they engage in reflective inquiry into the underlying causes, particularly concerning their own attitudes, motivation, and responsibility for learning. These reflective processes are clear indicators of double-loop learning.

Unexpected Findings

Learning Moments Before, During and After Teaching Sessions: Source for Two-Way Learning

Insights provided by the Reflectometer facilitated some unexpected learning not only affecting participants thinking, feeling and understanding, but also behavior. In the radiography CT skills training session, the teachers realizing that about one third of the students did not report learning moments during one of the learning sessions led to a reassessment of instructional strategies, resulting in a greater emphasis on practical, hands-on skills training.

Another unexpected yet important finding was that students reported rich and meaningful learning experiences not only during the formal sessions, but also in the time before and after them. Access to this broader and qualitatively deeper spectrum of learning moments provided valuable insights for teachers – insights that would likely have remained hidden through teaching alone. As the following example illustrates, significant reflection and learning often occurred after a session, particularly when participants engaged in discussion with peers or partners:

"Came home and talked with my partner about what I had learned. It gave me the opportunity to think more thoroughly about what I had learned, especially reflecting on the two previous events I had drawn, and I believe that helps me remember it even better."

These informal conversations took place immediately after the session, during car rides home from the mountain, or later in domestic settings. Some students even began submitting Reflectometer entries based on learning experiences from private, self-initiated activities outside the formal teaching context (Case 2), further highlighting the tool's relevance beyond structured educational settings:

> **What happened:** "Trip with student 8."
>
> **Thoughts:** "Is the avalanche risk here higher than participant 8 thinks? Could the wind-drifted snow trigger an avalanche when we reach the release zones? Is the snowpack stable enough? Should we turn around?"
>
> **Feelings:** "Fear and confidence at the same time."
>
> **Do/actions:** "Spoke up, discussed the situation thoroughly, continued on. Then said stop – let's turn around – but changed my mind and eventually went straight up. Was rewarded with powder."
>
> **Any notable consequences:** "A sense of mastery, but also gained insight into the importance of trust and communication within the group."

Recognizing the value of these pre- and post-session learning moments, teachers began incorporating structured reflective debriefs at the end of each day. This adaptation aimed to formalize and support the kinds of reflection participants were already engaging in informally.

In essence, by shedding light on what was happening when learning occurred – or failed to occur – the Reflectometer proved to be a powerful instrument for two-way learning. It enabled not only student reflection, but also offered teachers a window into the learner's experience, allowing them to learn from their students in return.

Discussion

Does the tool do what it was designed to do?

A hallmark of an effective tool is its ability to fulfill its intended purpose. In this case, the Reflectometer was developed to address the objectives outlined in our three research questions, which serve as a reference point for evaluating its utility and impact.

As demonstrated in the examples from both cases, the Reflectometer effectively captures a wide range of learning experiences, including their associated intensity and qualitative dimensions such as thoughts, feelings, and actions (RQ1). This multidimensional data allows educators and researchers to identify, assess and differentiate between various types of learning experiences – in our case, *Key Learning Moments* (KLMs) and their subcategories, *Dislocatory Moments* and *Key Memorable Events* (RQ2).

Furthermore, the Reflectometer provides insight into the depth of reflection prompted by these experiences, enabling an assessment of whether single- or double-loop learning was stimulated (RQ2). By giving teachers access to rich, learner-generated data – often including learning that occurs outside formal teaching sessions – it expands their understanding of when, how, and why learning takes place.

In addition, the Reflectometer serves as an assessment and developmental tool. By gaining insights into the quality of the students' learning experiences and processes, and comparing learning intensity graphs, teachers can identify discrepancies between expected and actual learning, allowing them to adapt and respond accordingly. In this way, the Reflectometer becomes a vehicle for two-way learning: it facilitates teacher responsiveness while simultaneously encouraging students to engage in meaningful reflection on their own learning experiences (RQ3).

Just as one could open a can of beans with a machine gun or attempt to cross an ocean in a bathtub, any tool – including the Reflectometer – can be misused or applied in ways far removed from its intended purpose. However, when used appropriately and in alignment with its design, the Reflectometer proves to be a powerful instrument for capturing and analyzing the qualitative dimensions of learning experiences. It offers valuable insights for both students and teachers, supporting deeper reflection and a richer understanding of the learning process. In doing so, it facilitates the teaching of reflective practice – a task often recognized as challenging for both educators and learners alike (8,9).

Limitations and Possibilities: What we Have Learned and the Way Forward

Building on the important work of Hetland and Vittersø (17) we developed and tested the Reflectometer across two distinct educational contexts: radiography education and avalanche training, thereby addressing the need of a reflective tool tested across multiple contexts pointed out by Préfontaine et al. (15). While further testing and evaluation in a wider range of settings is undoubtedly needed and wanted, the replication of our qualitative

analyses and findings in both cases strengthens the tool's credibility, consistency, and robustness as a method for capturing and analyzing learning experiences.

The Reflectometer's strong ontological and theoretical grounding in experiential (18) and transformative learning (19) theories – alongside key concepts such as double-loop learning (20-23), reflection, Key Learning Moments, Dislocatory Moments (20), and Key Memorable Events (24) – contributes significantly to its conceptual coherence, practical relevance, and analytical value.

In terms of construct validity – whether the tool measures what it was designed to measure – we found that the Reflectometer reliably captured a usefull type of data needed to analyze learning experiences, including their consequences, such as whether they stimulated reflection and double-loop learning in both cases. Moreover, our findings indicate that the Reflectometer is a highly flexible tool that can be adapted to suit a variety of research questions requiring both intensity data and insight into the qualitative dimension of individual experiences. For instance, researchers can modify the questions participants respond to, tailoring them to specific contexts or learning objectives. Additionally, the visual format of the Reflectometer can be adapted – such as extending the y-axis below the x-axis – to distinguish between positive (above the x-axis) and negative (below the x-axis) intensities of experience. Thus, the construct validity of the Reflectometer depends on its alignment with the specific use case and the coherence between any adaptations made and the questions being addressed.

Does the Reflectometer capture all relevant learning experiences? Likely not. It captures only those experiences that participants are consciously aware of, can recall, and choose to report. Even though we attempted to have participants fill out the Reflectometer within 24 hours after a learning session this was not always possible due to practical and logistical reasons. The time interval between the learning experience and completing the Reflectometer will inevitably influence both what is remembered and how it is recalled, as memory is reconstructive and susceptible to decay and distortion over time (25,26). However, as sketched out in Section 2.1, the Reflectometer does succeed in capturing learning processes from multiple perspectives – particularly how a learning session is experienced by both teachers and students. This includes areas of convergence, where expected learning outcomes align with students' reported experiences, as well as areas of divergence, where gaps between intended and experienced learning emerge.

One of the barriers to using the Reflectometer was the limitation of the paper-based format, which provided insufficient space for participants to elaborate on the additional questions – particularly when multiple learning moments were reported. Moreover, physical templates were sometimes lost, and in several cases, handwriting or layout issues made the data difficult to read and analyze. In the avalanche training context, some participants chose not to use the provided templates and instead submitted their own versions. While this creative approach was encouraged to support data collection and participant engagement, it

introduced challenges for analysis – especially in terms of intelligibility of the data. The variation in formats made it difficult to analyze and rendered graphical comparisons across participants impossible.

Some avalanche course participants voluntarily submitted Reflectometer entries based on private, informal tours that were not part of the official course curriculum. This effort and unsolicited use did not yield any extra credit for the participants, suggesting that participants found it personally meaningful and relevant beyond the boundaries of formal instructional contexts.

Further Testing in Diverse Learning Contexts: An Open Invitation

To address the limitations and barriers of the paper-based version and to support broader application and improved usability across diverse educational contexts, we developed a digital version of the Reflectometer. Inspired by emerging digital approaches to reflective tools (12,14) this version includes a data export function and customizable features adaptable to specific courses or learning sessions.

The digital Reflectometer overcomes several limitations of the paper-based version, including restricted space for qualitative input, legibility issues due to handwriting, and the risk of data loss. It is accessible through a web interface on any personal computer, tablet, or smartphone – though for optimal use, particularly when drawing intensity graphs, a larger screen is recommended.

The tool is freely available, and all data are securely stored on encrypted university servers. Importantly, users retain full ownership of their data. The digital Reflectometer is under continuous development, and we warmly invite educators, researchers, and practitioners to explore its use within their own learning contexts and to draw their own conclusions. Future research directions may include efforts to quantify findings, conduct longitudinal studies to evaluate the Reflectometer's effectiveness over time, apply the tool across diverse educational contexts to assess its generalizability, and incorporate student feedback to examine its usability and impact on learning. We are also eager to learn from the community and welcome insights into the creative and diverse ways the tool is being applied and tested. The digital Reflectometer can be accessed at reflectometer.eu.

Conclusion

This paper introduced the Reflectometer as a tool for capturing and assessing the intensity and quality of students' learning experiences. Tested in two distinct pedagogical contexts – radiography education and avalanche training – the Reflectometer effectively allowed identification and assessment of Key Learning Moments, including both affirming and dislocatory experiences, and provided insight into reflection and double-loop learning.

By visualizing when and how learning occurs – including before and after formal sessions – the tool supports both student reflection and teacher insight. This enables educators to identify and respond more effectively to challenges related to student learning and suboptimal course design. While not without limitations, the Reflectometer has proven adaptable and meaningful across settings. With the development of a digital version, it is now more accessible and easier to implement.
We invite educators and researchers to explore its use in other learning contexts. The tool is freely available at reflectometer.eu.

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Statements and Declarations

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Supplemental online material
The paper version of the Reflectometer is available at:
https://osf.io/a65r3/?view_only=7f102d594d794b9db0ea0589f9cb7ae1

Declaration of interest statement
TD and RF own and operate a private company offering avalanche courses in their spare time.

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