METHOD-BASED LEARNING: A CASE IN THE ASPHALT CONSTRUCTION INDUSTRY

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As in many domains in the construction industry, traditional working practices lean heavily on the onsite experience and craftsmanship (tacit knowledge) of operators and teams. This results in implicit individualised learning and lengthy learning cycles. To develop a deeper insight into construction processes, this tacit knowledge needs to be made explicit to instigate a change towards explicit method-based learning. For the asphalting industry, Miller (2010) developed a framework to make processes that take place on the construction site explicit when implementing new technologies. To change to explicit method-based learning, the experiential learning model of Kolb (1984) was introduced into current practices and 'explicating the process' was added to the learning cycle. Further, 'reflective observation' and 'abstract conceptualisation' were explicitly incorporated into current asphalting practices using feedback sessions with an asphalting team. This learning cycle was introduced during an actual construction project on a highway in the Netherlands. The adopted learning framework was found to be applicable and useful in the quest for improved process and quality control. By explicating the construction process 'as constructed', it became possible to have a meaningful discussion with operators in a feedback session and unravel their intentions and reasoning with the chosen strategies. Explicit method-based learning, as here, leads to improved quality awareness, better understanding of the processes and their interdependencies, and improved communication with and within the asphalting team.

Keywords: asphalt, experiential learning, feedback, operational strategies, quality control.

INTRODUCTION

Significant changes are currently occurring in the construction industry, resulting in changing roles for agencies (clients) and contractors. Further, agencies are shifting towards service-level agreements with lengthy guarantee periods. Within these new roles and contracts, contractors are directly confronted with any quality shortcomings that appear during the guarantee period. Therefore, it is important for contractors to improve process and quality control during construction.

In the current age of the internet, pervasive networks and rapid progress in technologies, one might expect contractors to embrace the new ICT opportunities for performance enhancement. However, in reality, the construction process is still mainly carried out without the use of high-tech instruments to monitor key process

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parameters, and little research effort has been put into the systematic mapping and analysis of construction processes. So, contractors hardly know what transpired during construction, and how the operations were carried out, and therefore it is near impossible to identify poor and good operational practices. Further, if the construction process is not explicit, the causes of any failures to meet the required specifications cannot be traced back to operational strategies on the construction site. The current operational strategies in the construction industry lean heavily on the skills and experience of operators on the construction site. Operators may implicitly learn based on experience from previous construction projects, but this is based on limited observations and data. Operators also receive little feedback on their work or the work and results of others, resulting in implicit learning (i.e. tacit knowledge) and lengthy learning cycles.

To enhance learning and improving the construction process in order to achieve better process and quality control, it is essential to move away from the current implicit individual learning towards explicit method-based learning. Given that current asphalting practices largely lean on the onsite experience of operators, it seemed appropriate to adopt and introduce the experiential learning lens of Kolb (1984) to current practices. This paper discusses a method to instil a change towards method-based learning and demonstrates its merits during the construction of an asphalt highway in the Netherlands.

The next section of the paper hones in on learning in the construction industry, followed by the research's aims and methodology. Next, the various phases of the learning model will be described for the highway project. Finally, the main conclusions and suggested directions for future research, specifically for the road construction industry but also the construction industry in general, will be discussed.

EXPERIENTIAL LEARNING IN CONSTRUCTION

Current operational-level learning practices in the construction industry are mostly based on the hands-on experiences of operators, and these experiences amount to active experimentation on how various strategies influence quality parameters (Figure 1). This is a form of individual and implicit learning, and results in lengthy learning cycles because of limited experiences and projects, and many changing variables. This characteristic of the construction industry makes learning and improving difficult, especially as the variables are often only implicit. To improve process and quality control, a change is needed, from the described individual implicit learning towards explicit method-based learning.

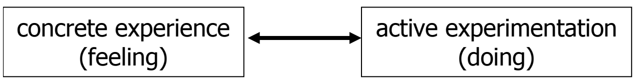

Figure 1: Individual implicit learning in the construction industry

The experiential learning cycle of Kolb (1984) was adopted in an attempt to move from individual implicit learning towards explicit method-based learning. In experiential learning theory, experience plays a central role. This is different from the cognitive view that emphasizes acquisition, manipulation and recall of abstract symbols, and from the behavioural view that denies any role for consciousness and subjective experience. According to Kolb (1984), experiential learning centres on the transformation of information into knowledge, an event that takes place after a situation has occurred and entails a practitioner reflecting on the experience, gaining a general understanding of the concepts encountered during that experience and then testing these general understandings in a new situation. Several other authors have also argued that learning takes place in this order (Brock and Cameron 1999, Daft 2000). For the construction industry, reflective practice models are seen as necessary but often found to be lacking (Orange et al. 2000). Several researchers have confirmed the importance of reflection and stress that reflection is an important facilitator and contributor to learning (Schon 1983, Boud and Walker 1998, Harrison et al. 2003).

Current learning processes mainly concentrate on the 'concrete experience' and 'active experimentation' parts of the experiential learning cycle, while 'reflective observation' and 'abstract conceptualization' are neglected. This neglect is mostly because the operational strategies and key parameters are not explicit, and not systematically monitored and mapped. Therefore, in this research, we have added monitoring (i.e. explicating) the process to the experiential learning cycle of Kolb (Figure 2). Further, a comparison can be made between the concrete experience (feeling) of the operators and the monitored process (data). In addition, 'reflective observation' and 'abstract conceptualisation' should be added to the learning cycle in order to improve quality and process control and to develop additional learning and reflective competencies within construction teams.

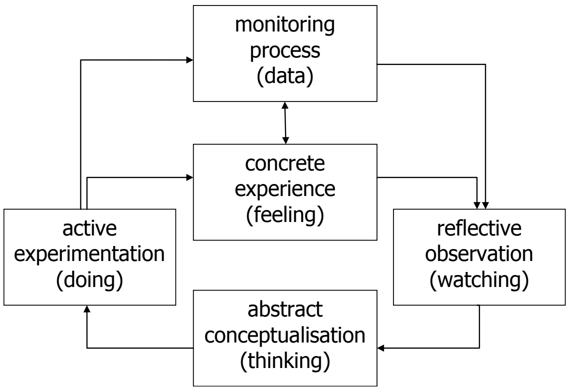

Figure 2: Monitoring (explicating) process in the experiential learning cycle of Kolb (1984)

AIMS AND RESEARCH METHODOLOGY

The aims of this research are firstly to include ‘reflective practice’ and ‘abstract conceptualization’ in current learning practices through conducting feedback sessions with operators to reflect on their work and their collaboration with others and, secondly, to enable explicit learning for operators based on the monitored process and the subsequent feedback session. The goal of this paper is to demonstrate the adopted method-based learning framework in use in an actual road construction project. During the construction of the a Dutch highway, the learning phases were incorporated into current practices and the full experiential learning cycle was monitored. Two nights of asphalting were monitored and observed, with a one-week gap between during which a feedback session was held.

Before the construction task started, a questionnaire survey was conducted with operators on how they planned to conduct their tasks. Next, the actual working methods were mapped 'as constructed' (concrete experiences). In mapping the actual working methods and making the construction process explicit, we used a previously developed measurement framework: 'Process Quality improvement' (Miller 2010). The operational activities were made explicit using several technologies, such as D-GPS to record machinery movements and a laser line-scanner, infrared cameras and thermocouples to record the asphalt temperature during the construction process. Both of these are important parameters in determining asphalt quality. In certain locations, the changes in density after every roller pass were measured. More information about the technologies that were used in working with this framework and the systematic way in which data were collected, analysed and mapped are described in Miller (2010) and preliminary results were presented at ARCOM 2008 (Miller et al. 2008). This data was used to make the process explicit, and a feedback session was then organized with the asphalt team. In this session, the intentions and reasoning of the operators regarding the process 'as constructed' were made explicit (reflective observation). Based on the 'as constructed' process and the feedback, a list of possible learning aspects and improvements were addressed (abstract conceptualization). During the second asphalting night any changes in strategies, quality and process awareness, and learning effects were experimented with and monitored (active experimentation).

LEARNING-CYCLE RESULTS DUTCH HIGHWAY PROJECT

Project description

The object of the case study was the construction of the A15 highway as part of improving the connection between the Port of Rotterdam and the rest of the country. A consortium of three contractors was responsible for the construction, and also for maintenance until 2035. Therefore, controlling the process and the quality was essential in order to prevent problems during the maintenance period. The construction work took place overnight (between 11 pm and 6 am). During the two measurement nights, the same team was working on the asphalting. The full experiential learning cycle is discussed below based on the explicated process.

Concrete experience

The laying temperature of the asphalt mixture, the cooling process and temperature variability are key quality parameters (Miller 2010). Despite this, during the construction process, operators receive virtually no information about these temperatures and their variability. So, in general, the operators have to estimate the temperature at a certain time based on their experience, relate this to the weather, the specific mixture and layer thickness. Before the measurement process, questionnaires were distributed among seven operators to seek their estimates of the temperatures. Then, during construction, four sets of measurements were made using thermocouples and IR-cameras to monitor the cooling process 'as constructed'. The operators' predictions and the measurements are shown in Table 2.

Table 2: Predicted and actual asphalt temperatures and cooling rates (measurement 1)

Parameter	Predicted range (7 operators)	As constructed (4 measurements)
Cooling until 120 °C (min.)	10-30	8-17
Cooling until 90 °C (min.)	24-60	22-38
Cooling until 60 °C (min.)	30-90	57-80
Difference surface and in-asphalt temperature (°C)	17-25	8-15
Temperature drop truck change (°C)	5-8	5-10
Temperature drop 3 min. paver stop (°C)	10-12	10-20
Temperature drop 7 min. paver stop (°C)	14-20	25-35
Temperature drop 15 min. paver stop (°C)	20-30	35-50

Interestingly, the measured cooling times to 120, 90 and 60 °C all correspond reasonably well with the operators' predictions. However, the range of predictions is certainly wide, for example one operator predicted that cooling to 60 °C would take 30 minutes, while another predicted 90 minutes. The difference between the surface and the in-asphalt temperatures was slightly overestimated by the operators. Further, the temperature drops during truck changes and paver stops were accurately predicted for the short stops, but underestimated for the longer (7 and 15 minutes) stops.

Additionally, the planned operational strategies regarding the number of roller passes and the temperature windows in which one could compact were sought before the measurement phase. During the construction process, the actual number of roller passes and the temperatures present when compacting were determined via D-GPS, infrared cameras and thermocouples. The results of the planned operational strategies and the actual operational strategies are shown in Table 3. From the data, it is clear that operators were able to predict the number of roller passes quite accurately for their own roller, but predicting the number of roller passes of their colleagues seems difficult. For example, operator 3 expected to make five or six roller passes himself, and during the measurement night he made between four and seven on the various parts of the new surface. However, operator 3 predicted that the other operators would both complete ten roller passes, but in practice operator 1 made four to six roller passes and operator 2 made seven to nine passes. The data also show that the temperature windows were somewhat difficult to predict.

Table 3: Expected and actual number of passes and temperature windows (measurement 1)

Parameter	Prediction operator 1	Prediction operator 2	Prediction operator 3	As constructed (4 measurements)
Number of roller passes Roller 1	2-3	2-3	10	4-6
Number of roller passes Roller 2	4	6-8	10	7-9
Number of roller passes Roller 3	3-4	2-3	5-6	4-7
Temperature window Roller 1	150-120 °C	140-120 °C	145-90 °C	150-125 °C
Temperature window Roller 2	130-90 °C	110-80 °C	90-70 °C	130-95 °C
Temperature window Roller 3	90-60 °C	70-50 °C	70-50 °C	90-60 °C

As such, the analysis shows that the estimates based on 'concrete experience' by the operators correspond quite well with the process 'as constructed' regarding their own operations (albeit that the estimates covered wide ranges). However, it was clearly difficult for operators to estimate what their colleagues were doing during the construction process. This makes it difficult to anticipate during the process and, as asphalting is a collaborative process, this will negatively influence the process control.

Reflective observation

A key step towards explicit method-based learning is providing feedback to the operators of the asphalt team and for them to learn from this feedback (Kolb 1984, Miller 2010). During the feedback session, the measured data were provided to the asphalt team so that they could reflect on their own operations. These sessions enabled teams to determine improvements in the asphalting process in both their individual tasks and their collaborative work. The measured quantitative data are used to make the operational behaviour explicit, and the qualitative data from the feedback sessions tells the story from the operators' viewpoints. The session lasted approximately one hour. The results of the measurements of the process 'as constructed' were printed and given to everybody so they could take a look at the findings themselves. Besides the asphalt team, also project managers, people from the preparation and technologists were present. The observations and reflections are summarised in Table 4.

Table 4: Observations and reflections of the operators of the asphalt team

Topic	Observation	Reflection asphalt team
Initial surface temperature	In general, the surface temperature behind the paver was 160 °C. During a truck change it cools by 5-10 °C. If the paver has to stop, the temperature decreases quickly (by up to 40 °C).	It is well-known that the temp. decreases by 5-10 °C during truck changes. The rapid temp. drop by 40 °C during paver stops was more than expected. If they are aware of lower temperatures, they will start compacting more quickly.
Cooling	The predictions of the operators agreed well with the measured cooling curves. Nevertheless, the range of predictions is rather large.	The differences in predictions are mainly caused by the variations in experience. Predictions by inexperienced operators are the least accurate.
	The variability in the cooling curves is rather large, making it difficult to predict the temp. during the process.	The operators knew this and stressed that this makes their work difficult. Real-time temp. information would certainly help.
Compaction strategy	Operators can fairly accurately predict the passes they will have to make but are less good at predicting the passes their colleagues will make.	It is difficult enough to do their own compaction consistently with so many changing variables. Real-time info about their colleagues could improve quality.
	The influence of the third roller on the final density is unclear. There is hardly any change in density despite the large number of roller passes.	Normally only two rollers are used in such projects rather than three. However, here, the project consortium insisted that three rollers were used to compact the asphalt.
	Rollers 1 and 2 were used consistently, but the spread in the number of passes by roller 3 is rather large.	The reason for the variability with the third roller is that the operator cannot see where the roller has been. The first and second roller operators can see this in the asphalt.
Cores and quality	The correlation between the onsite nuclear measured density and the core density determined in the laboratory is good (within 1%).	The correlation is rather good, but a technician is not always present at the site and sometimes at the wrong times, such the end of the night. This can be improved.
Paver speed	The speed of the paver is higher than in many other projects and above the expected speed.	The increased speed of the paver is not the operators' choice, but stipulated by the consortium due to production pressures.
	If the paver increases speed, the rollers have to work faster, but should be further away from the paver to operate in the same temp. window.	The asphalt team found this reasoning difficult to understand. Training that address various scenarios could possibly help improve this understanding.
Monitoring	The measurements provided the asphalt team with more information and formed a good basis for reflecting on the process.	The data often confirmed the team's gut-feelings. To understand the process better, more measurements should be conducted with various mixtures and ferent conditions.

Abstract conceptualization

The observations and reflections were distilled into 'abstract concepts' that produced plans for action which could be 'actively experimented' with during the second night of study. Plans at the operational, project, organizational and research levels were distinguished:

Operational level (asphalt team)

- The asphalt temperature throughout the whole construction process is important. Therefore, asphalt temperature information should be available in real-time and communicated between the technologists and the operators.
- Currently, asphalt technologists only systematically measure the density during compaction, plus ad-hoc temperatures. These technologists should also systematically measure the temperature and the number of roller passes and communicate these with the operators.
- The three-drum roller (the 3rd roller) is used to create an even surface. However, it hardly influences the density of the asphalt mixture and sometimes even compacts it at too low temperatures creating micro-cracks. Therefore, making fewer roller passes with the three-drum roller should be tried during the next measurement.

Project management level (work preparation and coordination)

- The managers realize that asphalt temperature is important for the operators. They also acknowledge that real-time information is essential to improve the process. The managers now consider buying infrared pistols for every roller operator (a low-cost option) and will try to convince the company to buy high-end equipment to continuously monitor real-time temperatures.
- The managers also recognize that it is difficult for the 3-drum roller operator to see where he has been. They acknowledge that GPS-based equipment could help with this problem, but argue that this is a significant investment and that more support from within the consortium and company is required. The data collected could help convince people about the need for new equipment.

Organizational level (company)

- At the organizational level, it is acknowledged that production pressures can lead to communication and quality issues, especially if there is little feedback. For example, while a higher speed may be possible, the previous experience of the operators is not based on higher speeds. Training and scenario-playing could possibly improve this understanding and experience.
- There is hardly any feedback between the laboratory and the technologists, despite both conducting density measurements. Feedback cycles should be included in quality control to compare the onsite nuclear-measured density and the lab-determined density in order to improve instructions for roller operators.

Research (R&D)

- The data collected should all be geo-referenced. Using geo-referenced data, a historic record of the road can be assembled, such as how it was constructed, how it behaves during usage, and where early damage might originate.
- Using the PQi framework, only density measurements are taken after every roller pass. However, using this strategy, it is not possible to understand what happens with the asphalt between operations. Therefore, during the next testing night, measurements should also be taken between the roller passes.
- Providing the individual operators with the graphical data on paper in front of them in the feedback sessions worked well. Previous feedback sessions were held using a beamer, but operators seem more focused if they have all the graphs and information in front of them.

The action plans for the project management and organizational levels have more of a mid- to long term perspective, whereas most of the operational-level plans could be quickly operationalized. During the second night of measurement, some of the short-term action plans were actively experimented with, as discussed in the next section.

Active experimentation

During the second measurement night, questionnaires were again used to establish how the operators planned to conduct their work, and again the construction process was monitored and observed. These plans were compared to the predictions for the first night. Two plans drawn up during the abstract conceptualization phase were actively experimented with during the second night: (1) fewer passes with the three-drum roller combined with density measurements between roller passes; and (2) feedback and greater communication during the process to see if this leads to improved predictions and understanding of the process.

Figure 3 shows the roller passes and density progression using the various rollers on measurement night 1 (left) and measurement night 2 (right). These figures demonstrate that many fewer roller passes were conducted with the three-drum roller during the second measurement night (two compared with seven on the first night), an aspect discussed during the feedback session. The figure also shows the density measurements made between the roller passes (the non-coloured blocks). This shows that, even between the roller passes, the asphalt mixture is still settling and expanding. As such, measuring between the roller passes also provides valuable knowledge about the asphalt behaviour during compaction.

We do not know which compaction strategy is better since no mechanical properties were determined (this was not the focus of the research). However, this example does show that, based on the explicated process, it is possible for operators to change their behaviour and to actively experiment. Based on the operators' experimentation, the new process can then be either adopted or rejected.

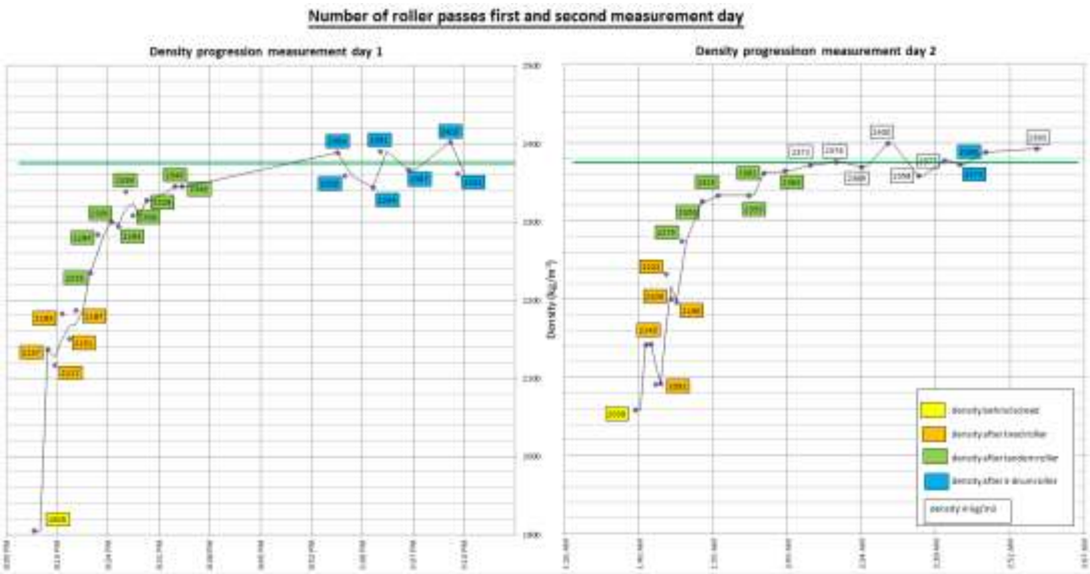

Figure 3: Density after each roller pass: first night (left) and second night (right)

The second element of active experimentation was to test if feedback and greater communication during the process would lead to improved predictions and understanding about the process. During the second measurement night, more intensive communication was observed (mainly as a result of being recognised as valuable during the organized feedback session rather than through instructions to operators). Roller operators communicated about temperatures and the number of roller passes. The technologist also communicated in more detail: in addition to the traditional density, the number of roller passes and the temperatures were also communicated. The results related to the predictions of the operators and the actual constructed process on the second night are shown in Tables 5 and 6. Based on these questionnaires and measurements, it can be concluded that, following the feedback session, the operators have improved their predictions of temperatures, cooling and number of roller passes compared to the first measurement night. The predictions made by the operators regarding temperature and cooling are now all within the range of those measured during actual construction and also within smaller bands. In terms of the number of roller passes and the temperature windows for compaction, most of the predictions corresponded with the actual construction process or were very close.

Table 5: Predicted and actual asphalt temperatures and cooling rates (measurement 2)

Parameter	Prediction range (7 operators)	As constructed (4 measurements)
Cooling until 120 °C (min.)	10-20	12-17
Cooling until 90 °C (min.)	20-40	19-29
Cooling until 60 °C (min.)	40-80	47-56
Difference surface and in-asphalt temperature (°C)	10-20	7-15
Temperature drop truck change (°C)	5-10	5-10
Temperature drop 3 min. paver stop (°C)	10-20	10-20
Temperature drop 7 min. paver stop (°C)	20-40	20-30
Temperature drop 15 min. paver stop (°C)	30-60	30-50

Table 6: Planned and actual number of passes and temperature windows (measurement 2)

Parameter	Prediction operator 1	Prediction operator 2	Prediction operator 3	As constructed (4 measurements)
Number of roller passes Roller 1	6-7	3-4	5	4-7
Number of roller passes Roller 2	7-8	5-6	6	6-7
Number of roller passes Roller 3	4	2-3	2-3	2-4
Temperature window Roller 1	150-120 °C	150-130 °C	150-130 °C	150-125 °C
Temperature window Roller 2	130-80 °C	130-90 °C	130-90 °C	135-90 °C
Temperature window Roller 3	70-50 °C	70-50 °C	70-50 °C	70-60 °C

CONCLUSIONS AND FUTURE RESEARCH

Given the various changes taking place in the construction industry, it is becoming increasingly important to control the process and improve quality control. Current construction processes however lean heavily on the skills and onsite experiences of operators. This essentially results in individual implicit learning and lengthy learning cycles. In this paper, the experiential learning theory of Kolb (1984) was introduced to usher in a change towards explicit method-based learning. Explicating onsite construction processes was added to the learning cycle, and demonstrated in the asphalt industry. To enhance the learning process, more explicit operational data were provided to the operators.

Transparency in the process and operational choices were created using new technologies that provided understandable visuals that helped in the sensemaking by individual operators and the team. The adopted learning framework was shown to be applicable and useful in a Dutch highway project. By explicating the process 'as constructed', it became possible to have a meaningful discussion with the operators of the asphalt team in a feedback session and so unravel the intentions and reasoning of the chosen strategies. This explicit method-based learning led to improved awareness, of both quality and in general, and communication with and within the asphalt team. It helped to fill the gap in 'explicit learning and reflection' in the construction industry and offers a method for developing the learning and reflective competencies of teams such as those investigated here.

This explicit method-based learning approach may also be applicable to other traditional experience-driven practices in the construction industry. For example, in the sub-surface domain (i.e. laying cables and sewers), where the process is similarly not explicit, multiple stakeholders influence the process and coordination is becoming increasingly important. Also, further research is planned to study behavioural changes after a second or further learning cycle. The learning styles defined by Kolb (1984) for various types of people could be useful in studying these learning cycles. Knowing and understanding the different learning styles could shorten the learning curve. It has also been observed that certain asphalting teams perform better than others under certain circumstances. Further research is planned to understand why certain teams perform better than others. A possible lens through which to investigate this is the perspective of 'High-Reliability Crews' (Mitropoulos 2009). Identifying the rules and work practices of high performing asphalt crews could help to achieve higher levels of production, quality and safety across the sector. This would be a valuable step in the quest towards improved process and quality control.

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