How do students regulate their learning in challenge-based learning?

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HOW DO STUDENTS REGULATE THEIR LEARNING IN CHALLENGE BASED LEARNING? AN ANALYSIS OF STUDENTS' LEARNING PORTFOLIOS

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ABSTRACT
Self-regulated learning (SRL) is one the key pedagogical principles of Challenge-based Learning (CBL) in engineering curricula. Students in CBL have the primary responsibility for planning, implementing, and evaluating their effort and progress. This study explores the use of learning portfolios as a pedagogical tool aimed to document students' SRL in a CBL course for 1st year engineering students. The research question was: How is SRL documented in a personal learning portfolio during a CBL course? Students were expected to work for 9 weeks with a group of peers on an open-ended challenge. Students were asked to complete a learning portfolio at 3 moments. In week 1, they were asked to set, individually, 5 disciplinary

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and 5 professional goals they wanted to achieve and in week 5 and 9 they were encouraged to reflect on the progress and attainment of those goals. Twelve students' learning portfolios were included for analysis in this study. Content analysis of the learning portfolios revealed that students in week 1, described goal setting and in week 5 described SRL processes such as monitoring and self- evaluation while in the final submission in week 9, students reflected on the attainment of their individual goals and the overall success of their project, revealing a need for balancing their own disciplinary and professional goals and the overall goals of group they were members of. The study suggests that learning portfolios provide a useful instrument to encourage SRL in CBL. Limitations and implications for education and research are discussed.

1. INTRODUCTION

1.1 Self-regulated Learning in Challenge-based learning

Challenge-based Learning (CBL) is a student-centered pedagogy becoming increasingly popular in engineering curricula [1] [2]. In CBL, learning starts from an open ended, real life challenge and students are given the freedom to think out of the box and design a project directed entirely by themselves [2] [3]. This implies that students need to show increased levels of agency, autonomy, and self-directedness [2]. For example, a study by Membrillio et al. [3] involving real life, open ended challenges in collaboration with an external industry partner, found that students experienced difficulties in regulating their learning, due to the increased complexity and uncertainty associated with the course. This suggest that Self-regulated learning (SRL) is an essential skill for effective learning in CBL. However, the way students regulate their learning in a CBL context has not received adequate attention in the literature. Thus, the aim of the present study is to assess how SRL is documented by 1st year engineering students working in a CBL course.

1.2 Theoretical Background: Self-regulated learning

SRL can be seen as an umbrella term that which entails metacognitive processes such as goal setting and monitoring, motivational processes like self-efficacy, mastery goal orientation or intrinsic task interest and behavioral processes such as, attention sustainment, choosing and structuring the learning environment [4] [5] One of the most widely used models of SRL is the cyclical model by Zimmerman [4] that is characterized by 3 cyclical iterative phases: forethought, performance, and self-reflection [6].

The forethought phase describes the processes of task analysis and self-motivational beliefs that take place before students engage with learning. In this phase, self-efficacy, outcome expectancies, intrinsic interest, and goal orientations are important. In addition, in the forethought phase, students engage in task analysis, which includes goal setting and strategic planning. In the performance phase, students systematically and actively engage in learning. In this phase, self-control and self-observation are key processes. Students exhibit self-control by engaging in strategies such as imagery, self-instruction, attention focusing, and others targeted at reaching goals. Self-observation includes self-monitoring and self-recording of learning progress. In the final phase, self-reflection, students' use of self-monitoring and feedback from the previous phase to form self- evaluations (self-judgment) and attributions about the causes of their performance. Students also react

to their performance with self-satisfaction about achieving a certain goal and adaptive or defensive responses. Adaptive responses include adjustment and modification of motivational beliefs and task analysis, while defensive responses include emotional reactions to performances.

1.3 Portfolios and Self- regulated Learning

Portfolios represent a collection of evidence of students' learning [7] [8]. Portfolios are frequently used to support and document students' SRL processes such goal setting, monitoring or reflection [8] [9]. A study conducted by Mansvelder-Longayroux et al. [9] analyzed the content of student teachers' portfolios and made the distinction between in action-oriented and meaning-oriented activities described in portfolios. Action oriented activities describe what has been done and help students to become aware of what they know and what they are able to do. Meaning- oriented activities entail sense- making of an experience and understanding the underlying process of it. They found that students engage more often in action oriented activities when writing a portfolio. However, meaning oriented activities and reflection are also important for SRL and students' development, but students need additional support in order to reflect on their experiences [8]. A systematic review of the relationship between the use of portfolios and SRL suggested that influencing factors include students' supervision in SRL skills development, integration of portfolio into educational routine, regular coaching and scaffolding is provided to students to increase motivation, designing a portfolio to facilitate at least goal setting, task-analysis, plan implementation, and self-evaluation [7].

1.4 Research Question

The research question that guides the present study is: "How is SRL documented in a personal learning portfolio during a CBL course?" To answer this question, we analysed the written Personal Learning Portfolios that students wrote during a first year CBL course.

2. METHODS

2.1 Context and participants

For this study, we focused on one CBL course, taking place in Eindhoven University of Technology. This course is part of the educational initiative E3 (Eindhoven Engineering Education). In this course called E3-Challenge 1, first year engineering students from different disciplines can work collaboratively with a group of peers for 9 weeks on an open challenge, in which they can design, create and evaluate a product in the context of the UN Sustainable Development Goals. The challenges concern the following topics: Pulsar navigation, Wind energy storage, Healthy soundscapes in shared workspaces and Physics of life.
During the course, students were having meetings on a weekly basis with an expert on their case as well as weekly SCRUM meetings with a Teaching Assistant (TA) that supports them in group processes. By design this course is encouraging SRL by giving to students the primary responsibility for planning, implementing, and evaluating their effort and progress during the course. As part of the course, students were asked to write a portfolio to document their SRL at three times: in week 1, students had to set 5 disciplinary and 5 professional goals they would like to achieve during the course. In week 5 and week 9 they had to look back and on how they were progressing in achieving those goals. For all three submissions,

students received individual written feedback and advice from the course coordinator and teaching assistants aimed to facilitate their SRL. The feedback focused on encouraging students to re-evaluate their initial goals, plan and evaluate them as part of SRL.

2.2 Data collection

Writing the Personal Learning portfolio was a mandatory deliverable of the course that counted for 30% of students' final grade. After the end of the course, we asked from students' permission to analyze their portfolios. Out of 30 students participating in the course, 12 students consented to include their portfolios for analysis in this study, which resulted in 3 submissions per students, in total 36 submissions. The Ethics Review Board of the University has approved this study.

2.3 Data analysis

Following the theoretical model of Zimmerman [4], we developed 21 a priori codes, corresponding to all elements of SRL phases of forethought, performance and self-reflection to analyze students' portfolios. Twenty additional codes were developed to group students' disciplinary and professional goals in submission 1. Content analysis was conducted using ATLAS.ti [10]. The main researcher analyzed all portfolios and an auditing procedure among all researchers was conducted to discuss the results of the coding process.

3. RESULTS

According to our analysis, submission 1 of students' portfolios aligned with the forethought phase. Submission 2 had examples of performance and self-reflection phase and examples of new goal setting corresponding to the forethought phase. Submission 3 focused on self-reflection. All 12 portfolios mentioned goal setting in submission 1 (5 disciplinary and 5 professional goals), monitoring of all goals in submission 2 and self- evaluation of achieved goals in submission 3. Our analysis also suggested that several elements of the SRL model by Zimmerman [4] were not documented at all in students' portfolios. Those included: strategic planning, self- efficacy, outcome expectations, time management in the planning of activities, imagery, interest incentives and self- consequences. Table 1 summarizes the codes developed based on the model of Zimmerman [4] [5] and the additional codes developed by the researchers. Table 1 also provides a description for each code, their frequency and the number of students who reported them.

Table 1. Overview of codes identified in students' portfolios

SRL phases	A priori codes	Code explanation	Frequency	N of students	Portfolio submission
PHASE 1. Forethought Phase					
Task Analysis					
	Goal Setting	*Goals set by students*			Submission 1 (week 1)
		Disciplinary goals			
		Understanding of concepts/ development of disciplinary knowledge	33	12	Submission 1 (week 1)
		Coding (e.g., using MATLAB, Python)	8	8	Submission 1 (week 1)
		3D printing	8	8	Submission 1 (week 1)
		Application of knowledge	7	7	Submission 1 (week 1)
		Literature search skills	3	3	Submission 1 (week 1)
		Professional goals			
		Teamwork	11	11	Submission 1 (week 1)
		Presentation skills/writing skills	7	7	Submission 1 (week 1)
		Communication skills	7	7	Submission 1 (week 1)
		Time management	6	6	Submission 1 (week 1)
		Management of meetings (minute taking, being chairman)	6	6	Submission 1 (week 1)
		Project management skills	6	6	Submission 1 (week 1)
		Leadership skills	4	4	Submission 1 (week 1)
		Creativity	3	3	Submission 1 (week 1)
		Design thinking	2	2	Submission 1 (week 1)
		Critical thinking	2	2	Submission 1 (week 1)
		Reflection	2	2	Submission 1 (week 1)

		Flexibility	2	2	Submission 1 (week 1)
		Giving and receiving feedback	1	1	Submission 1 (week 1)
		Risk taking	1	1	Submission 1 (week 1)
		Problem solving	1	1	Submission 1 (week 1)
	Strategic Planning	*Development of an action plan and needed strategies to achieve their goals*	Not reported	Not reported	Not reported
Self- Motivation Beliefs					
	Self-Efficacy	*Students' belief about their capability to achieve their goals*	Not reported	Not reported	Not reported
	Outcome Expectation	*Students' belief about the probability to succeed in their goals*	Not reported	Not reported	Not reported
	Task Value	*Relevance of tasks for achievement of goals*	11	4	Submission 1 (week 1)
	Interest	*Personal liking and interest of performing tasks*	10	7	Submission 1 (week 1)
	Goal Orientation	*Students' beliefs about learning purpose*	3	3	Submission 1 (week 1)
PHASE 2. Performance Phase					
Self-Observation					
	Monitoring	*Students' cognitive process to assess performance*	120	12	Submission 2 (week 5)
	Self-Recording	*Students' recording of actions to achieve certain goals*	6	6	Submission 2 (week 5)
Self-Control					
	Task Strategies	*Students' use of strategies to complete a task*	4	4	Submission 2 (week 5)
	Self-Instruction	*Students' own efforts to learn a task*	4	4	Submission 2 (week 5)

	Imagery	*Students' mental organization of information*	Not reported	Not reported	Not reported
	Time Management	*Planning the use of time for a certain task*	Not reported	Not reported	Not reported
	Environmental Structuring	*Students' actions to create an environment that facilitates learning*	3	3	Submission 2 (week 5)
	Help Seeking	*Students' request for help to others (teachers and peers)*	6	3	Submission 2 (week 5)
	Interest Incentives	*Students' self-given messages to remind their goals*	Not reported	Not reported	Not reported
	Self-Consequences	*Students' self-praise and self-rewards*	Not reported	Not reported	Not reported
PHASE 3. Self-Reflection phase					
Self-Judgement					
	Self-Evaluation	*Students' self-assessment of own performance in achieving their goals*	120 6	12 6	Submission 3 (week 9) Submission 2 (week 5)
	Causal Attribution	*Students' explanation about their success and failures*	14 6	8 6	Submission 3 (week 9) Submission 2 (week 5)
Self-Reaction					
	Self-Satisfaction	*Students' affective and cognitive reactions produced by self-judgement*	11	9	Submission 3 (week 9)
	Adaptive/ Defensive Decisions	*Students' willingness to perform a certain goal or task again in the future and to activate learning strategies*	11	5	Submission 3 (week 9)

3.1 Forethought phase

The analysis of submission 1 revealed that students were all able to identify and describe relevant disciplinary and professional goals related to the course.
Sixty disciplinary goals and 60 professional goals were identified. One student reported as one of his disciplinary goals the development of project management skills, but we decided to include this goal under the professional goals category. This resulted in 59 disciplinary goals grouped in 5 categories and 61 professional goals grouped in 15 categories (see Table 1).
Regarding task analysis, even though goal setting was prominent in all initial submissions, planning was not mentioned, meaning that students did not provide any plan on how they aimed to achieve those goals.
Regarding, self-motivation beliefs, only 4 students explained why setting these goals would be beneficial for them in the future (task value) and 7 students elaborated on their personal interest in pursuing their specific disciplinary and professional goals (interest).
For example the quote below shows the way students formulated their goals, describing the task value of the selected goals and their personal interest in pursuing them.

> *I aspire to improve my knowledge of physics through the Applied Natural Sciences course, not only for the sake of this project, but also to develop a greater appreciation for real world phenomena and how they work (Student 1)*

Students showed in their initial submission enthusiasm and genuine interest to the content of the course as well as the challenge-based learning process which in their perspective gave them the freedom to pursue their interests in more depth and develop useful skills for their future career.

> *When I read about the [ ] course, I felt this was THE opportunity to invest my energy solving real problems through the fields of biology and physics, my favorite natural science fields. The innovative aspect of this project, was the main reason for me to choose this project. (Student 11)*

Finally, examples of forethought phase were also found in the second submission. After students monitored their performance in week 5 and reflected on their progress, 6 students adjusted their initial goals and set new goals that were more suitable for this stage of the course, taking into consideration time constraints, personal interest, and balance with group goals.
For example, a student had initially set a goal to learn MATLAB but in week 5 re-evaluated the goal and adjusted it:

> *I have never used Matlab before, as I study mechanical engineering. I hope to gain an understanding of how the program works and how to use it (Student 8, submission week 1)*
>
> *Given the work-distribution that my team has adopted thus far, this is a goal I have made little progress in(…)This is something I hope to work more on in the coming weeks, especially as the algorithm (based on matlab data) is developed. My hope is that I can assume a position of assistance and aid my group members with any MATLAB work they may have. I should note that the*

reason they have been focusing on MATLAB whereas I have not is simply because they were already experienced in it, so it made more sense (Student 8, submission week 5).

3.2 Performance phase

In submission 2, students had to look back at the first 5 weeks of the course and reflect on how they progressed with their self-set goals, while in the third submission they had to evaluate the overall learning experience after the end of the course. In both submission 2 and 3, all students used monitoring as a process to assess ongoing performance and achievement of goals. Six students elaborated on the actions they performed in order to achieve their goals (self- recording). This included recording how many hours they spent on each task they had to accomplish or breaking the tasks in smaller steps or prioritizing different tasks. Self- recording helped those student to realize that certain goals needed to be prioritized according to their importance and time availability. For example, if a task was considered less important for the course and very time consuming, it was receiving a lower priority.

Related to the goal of learning Siemens NX, this goal has unfortunately not been achieved due to a number of reasons. First of all the main reason it has not been achieved is due to the fact that it would not add much value to our project and time could better be spent on the coded aspect of our design rather than the physical (Student 6)

Four students mentioned self-instruction as their main strategy to achieve their goals.

For coding and 3D modelling I still need to watch more tutorial videos and keep practicing, as well as, learn more basics like Pandas. My plan to continue developing knowledge from the Applied Natural Science course is to often practice the exercises and hopefully maintain an average grade of at least 4 out of 5 for the quizzes (Student 1)

Because of our common Signals I course, I am able to better understand how frequencies can be managed and calculated. For example how an AM signal is propagated using a carrier frequency. As well as this, I have watched multiple online lectures on the topic and read some research papers. Using these, I have managed to create an antenna suitable for a TDoA (Time Difference of Arrival) RDF system (Student 5)

Regarding professional goals, such project management, other task strategies such as keeping notes, using calendars or using communication platforms to facilitate collaboration among team members were mentioned by 4 students.

Even though time management was an important goal for 8 students, none of the students were concrete in their planning on how to achieve them. As mentioned earlier, 6 students recorded the time spent in the accomplishment of certain tasks but they did not plan or adjust their time management for the coming weeks of the course.

Three students mentioned environmental structuring as important factor that influenced their learning. This was relevant to the fact that the course was taking

place online due to COVID-19, thus students could not go to campus or meet their peers or teachers in real life. Thus, students had to do several to make studying from home productive. Help seeking was mentioned in 4 instances in the form of asking teachers or peers for support for clarifying questions, or asking additional material like articles that were relevant to their challenge.

3.3 Self-reflection phase

In submission 2, students did not engage only in monitoring of current performance, but they also engaged in self-reflection about the suitability of their goals and the need for adjustment. In submission 2, 6 students realized that the initial goals they had set were either too vague or too ambitious and thus it was hard to assess their achievement. When evaluating their progress, students realized the importance of good planning.

> *Another thing I realized next time I have to make a better plan on how I am going to achieve my goals. This was the first time I really set learning goals myself, and now while looking back, I think I could have done better if I had made a better plan on how to achieve these goals (Student 2)*

Causal attribution for their goal success or need for adjustment were found in 6 student portfolios. Students attributed the need for adjusting their goals to time constraints and project specifications that were forcing them to pursue different goals that were more relevant for the project success.

> *I need to modify my goal of developing skills needed to combine physics and maths, and instead direct it more towards improving my abilities to model mathematical-physical equations (Student 1).*

When considering adapting their goals, two aspects played an important role: how clear and attainable their personal goals were at the first place and, secondly, whether their goals were still in accordance with the group goals.

Submission 3 helped students to reflect not only on whether their goals were attained or not but also on the reasons about it and on how this learning could be useful for their professional future. In this submission, 8 students reported causal attributions about the reasons of not accomplishing their initial goals, including conflicting goals with final project characteristics, limited time and setting too many and too ambitious goals at the beginning. Nine students reported positive emotions such as satisfaction, and pride associated with the successful accomplishments of tasks and achievement of goals.

> *This course has been a pleasure to participate in. I was engaged with the topic, learnt a lot and ultimately created a final product that I'm proud of (Student 8)*

Five students appreciated the opportunity to develop reflection as a skill for the course. They realized that looking back and evaluating how things went helped them to approach new tasks in a more efficient way. These 5 students also reflected on how this learning would be useful in their future and expressed their willingness to participate again in a CBL course to develop further their disciplinary and professional goals.

> *What I have found in this project is that, in order to conduct research that can clearly be applied, this needs to be decided in the initial stages of the project and needs to be included in the research question[…] A good observation in the midterm report is that the application needs to be included in the tasks to be appropriately explored, which happens if the research question aims in an applied direction […]Therefore, in the future it is important to know from the start what your team members aspire to do and through that knowledge decide what directions the research can go in (Student 13)*

Five students appreciated the value of reflection itself. They saw the importance of not only doing but also taking a step back and evaluate their work. For example, one student mentioned how reflection had helped him use the feedback of peers and teachers in a more constructive way.

> *Having practiced self-reflection before each peer review and after each meeting, I was able to reflect on the feedback for my mid-term goals and incorporate it into my final personal portfolio. Reflecting on the feedback also gave me a better understanding of how I could become a more effective team member (Student 10)*

4. DISCUSSION

In this study, we aimed to assess how SRL is documented in a portfolio that students had to produce in the context of a CBL course. According to the findings of the study, students were able to identify disciplinary and professional goals that were in accordance with the course but needed additional guidance on making the goals more specific, measurable, clear and suitable for the time frame of the course. In this study, goals acted as regulatory agents for SRL. Despite the fact that students were able to set relevant and coherent goals, they did not describe a concrete planning on how to achieve them in the forethought phase. That made goal attainment and evaluation harder for students.

In the performance phase, students had to reevaluate their goals, adjust them to time constraints but also negotiate and prioritize goals taking into considerations team goals in addition to their personal goals. This suggests that individual SRL processes might interfere with group processes taking place during a CBL course.
Thus, together with the concept of SRL, in CBL also the concepts of co-regulated learning (CRL) and shared regulated learning (ShRL) are relevant [11] [12].
In the final submission, students, described clearly which goals they achieved and which they did not achieve during the course. Writing a portfolio helped students making their learning process visible and explicit both to themselves and their teachers. They used the portfolio as a tool to look back on their experience and actions during the course and make explicit what they had done, what they learned and how they have progressed during the course. This is in accordance with the study of Mansvelder-Longayroux et al. [9] where the analysis of student teachers' portfolios revealed that they focused mostly on action oriented activities. In our study, few students reported that through the use of portfolio and documentation of SRL, they appreciated the value of reflection. As reflection plays an important role in SRL, encouraging students to use the portfolio as a tool for reflection can be beneficial for

students in CBL. In this case, students need additional support when reflecting on their learning process [7].

4.1 Recommendations for practice

The study suggests that SRL is important in CBL, and portfolio can be a useful way to facilitate the documentation of students' learning process. As reflection has self-regulatory function in the learning process and students should be encouraged to use the portfolio for documenting their learning process but also reflecting about it. In our study, we saw that several aspects of SRL learning were not mentioned at all by students. In that respect, the use of portfolio can be helpful but only if students receive support in writing in depth reflections. Reflective assignments can provide opportunities to dive deep into the processes that allow students to take control of their own learning [9].

4.2 Limitations and future direction for research

The study focused on a specific course and the included sample was small, thus more general conclusions cannot be drawn. Another limitation of the study is the focus only on SRL. Learning in CBL is not only individual but also collaborative, thus other forms of regulation such co-regulation, which occurs between students and teachers and socially shared regulation which occurs with a group of students are also relevant and should be explored. Future studies should explore the influence and experiences of the aforementioned social types of regulation as well [11] [12].

5. CONCLUSIONS

SRL is one the key pedagogical principles of CBL in engineering curricula. Students in CBL have the primary responsibility for planning, implementing, and evaluating their effort and progress. Combining writing a portfolio with additional support towards reflecting would be beneficial for students' learning in CBL courses.

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