Flow and Physical Objects in Experiential Learning for Industrial Engineering Education

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Abstract. The paper explores the impact of physical learning objects and learning styles on flow and learning outcomes in industrial engineering education. Learning is conceptualized with the theory of experiential learning. Comparitive case studies yield data involving more than 100 students since 2009. The findings provide a strong argument for utilizing physical objects in education consistent with construtionist theory. It is futhermore found that flow may have negative impact on the learning scope.

Keywords: Experiential learning, flow, serious play, case study.

1 Introduction

According to Riedel et al. [1] learning is in the curricula of operations management and industrial engineering primarily based on a one-way transfer of concepts and methods. Especially early stages of education in this field are prone to these “transmission” models of learning, where rather fixed ideas are floated into to the learner [2] and personal interaction as well as experimentation is limited.

Research on experiential learning yielded four (respectively nine) learning style types that help to develop curricula allowing for a greater variety of learning processes [2]. The consequent goal is to expose students to a variety of learning opportunities related to different learning styles in order to foster the individual realization of preferred learning processes in different course formats. Adequate learning processes may yield in turn that students immerse themselves into the activity being fully concentrated, absent-minded and even losing all sense of time. These characteristics pertain to what Csikszentmihalyi called flow [3] and seem desirable for effective and positive learning processes in institutions [4, 5].

A second starting point of this article is the notion of the hand-brain-connection rooted in the work of Penfield and Rasmussen [6] and its implication for learning highlighted by Papert’s theory of constructionism [7]. This theory may be summarized as learning-by-making and emphasizes that the material used during the learning process is decisive for deep engagement in the task [8], hence for entering the state of flow.

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The outlined conceptual building blocks are merged into three subsequent research questions.

1. Do different course formats, implying different learning styles, impact students' experience of flow?
2. How does course material impact flow?
3. How is flow linked to the learning outcome?

Figure 1 summarizes these questions and the given context. The research questions are intended to be explorative.

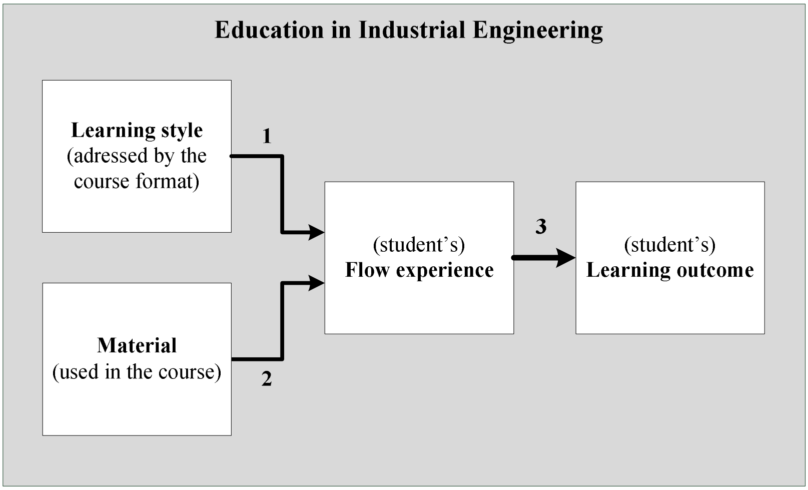

Fig. 1. Conceptual framework

The rest of the paper is structured as follows. We will give a brief review on experiential learning and flow theory first. A subsequent section provides an overview on the method and three case studies. Finally, preliminary findings and conclusions are discussed.

2 Theoretical Background

2.1 Experiential Learning

Experiential learning accentuates the learning process including the total person, e.g. their behavior, emotions and perceptions [2]. Knowledge is therefore created due to two distinct learning processes: The grasping and the transforming of experience [9]. Grasping may be conceptualized as a continuum between concrete experience and abstract conceptualization. Transforming spans from active experimentation to reflective observation.

Combining both process dimensions yields the classical four learning styles (diverging, assimilating, converging, and accommodating) [2] that can be expanded by the work of Abbey et al. [10] into nine styles [2]. We will reconsider these learning styles in order to classify the case studies in section 3.

2.2 Flow Theory

The state of flow is strongly linked to positive emotions and can be attained when task requirements and the abilities of the person match, the task is clearly structured, there is immediate feedback, and concentration is undisturbed [3, 11]. Experiencing flow during learning processes is supposed to be linked to improved learning outcomes [12].

Three major dimensions of flow are the control of the activity (control), the absence of mind during the activity indicated e.g. by losing the sense of time (absent-mindedness) and being focused on the activity (concentration) [11].

However, most studies of flow in education seem biased towards computer based games and neglect other types of "material" like physical objects [13].

3 Method and Case Description

We selected a case study approach due to the explorative nature of the study and multiple cases in order to explore contrasting differences concerning the learning types and material [14]. The underlying conceptual framework, in accordance to Miles and Huberman [15], is displayed in Figure 1. Data was collected by questionnaires, observations, and interviews with students. Table 1 illustrates the sampling logic and summarizes all three cases.

Table 1. Case Overview

	Case I: PS	**Case 2: LSP**	**Case 3: PPC**
Material	3D (Lego bricks, sensors and actuators, computer)	3D (Lego bricks)	2D (paper and pencil, computer)
Experience grasping	concrete experience (ce)	between ce and ac	abstract conceptualization (ac)
Experience transforming	active experimentation (ae)	between ae and ro	reflective observation (ro)

All cases have in common that they represent the exercise module of courses that contain classical "transmission" modules with oral lectures as well.

Case 1 is part of a course that teaches the fundamentals of facility planning and systems engineering, including requirements engineering and project management. Students are required to build in teams a production system (PS) based on Lego Mindstorms [1, 16, 17]. Figure 2 gives an impression of students building and programming their model. Data is sampled from five runs of the course involving approximately 90 students since 2009.

Case 2 belongs to an advanced course on leadership skills. Participants work in heterogeneous teams to model a shared understanding of leadership including the various facets of the topics, their personal experience and perceptions. Modeling is realized by means of abstract physical metaphors. The process utilizes a method based on Lego Serious Play (LSP) [8, 17, 18]. Figure 3 gives a workshop-impression. The analysis makes use of data from two courses with 25 students since autumn 2011.

Case 3 is the exercise of an intermediate course on production planning and control (PPC). Students learn e.g. how to calculate economic lot sizes, use a standard ERP-system and interpret characteristic curves of logistics and production systems. The course is established for almost ten years and mainly held by the second author of this paper. Our in-depth analysis includes 15 participants from the summer term 2012.

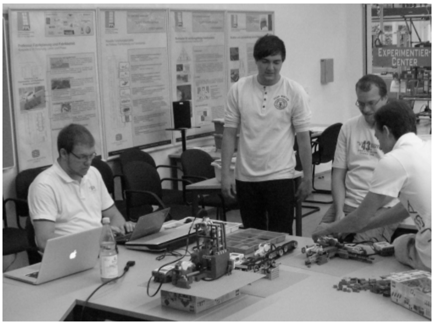

Fig. 2. Students working on their production system (case I)

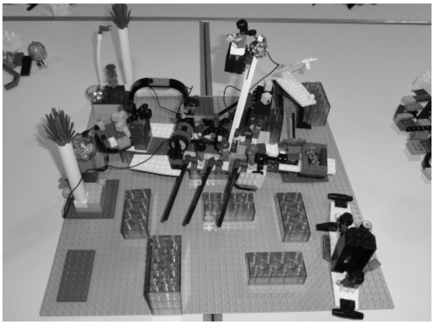

Fig. 3. Students' shared metaphorical model for leadership as a boat surrounded by high tides (case II)

4 Results

Preliminary findings indicate that students experience a high level of flow when experimenting with physical objects especially when combining it with technical problem solving (case 1). However, even more abstract and reflective settings like in case 2 evoke flow-like experiences. The descriptive statistics in Table 2 give evidence for this observation. The measurement is based on questionnaires with four point scales (1 – strong agreement … 4 – strong disagreement).

Table 2. Descriptive Statistics

Item	Case I: PS	Case 2: LSP ($N = 8$)	Case 3: PPC ($N = 15$)
The exercise was fun	$M = 1.69$* ($N = 88$)	$M = 1.63$	$M = 2.20$
I knew what to do (control)	$M = 1.80$ ($N = 5$)	$M = 1.75$	$M = 2.33$
I forgot time (absent-mindedness)	$M = 1.80$ ($N = 5$)	$M = 2.50$	$M = 2.73$
I was completely focused (concentration)	$M = 1.80$ ($N = 5$)	$M = 2.00$	$M = 2.80$

It is furthermore observable from Table 2 that the utilization of physical material tends to yield positive emotions ("fun") among students. An independent sample t-test showed a significant difference between the means of PS and PPC, $t(101) = 2.775$, $p = .01$ for the item "the exercise was fun". The eta square index ($\eta^2 = .07$) indicated a medium effect size.

Furthermore, most participants agree that physical 3D material helps them to express thoughts and explore complex technical systems. Participants for the LSP case were convinced that 3D models evoke richer communication ($M = 1.63$). One participant stated:

"I can use this serious play in creative discussion, where flip charts are too abstract."

Someone added that the models help when …

"defending your own ideas".

However, an estimated participants share of 10 to 15% tend to feel unconvertible using physical objects based on Lego bricks. One participant, who was certainly not in the state of flow according to his answers in the questionnaire, stated that he…

"[felt] like a child" and suggested *"to use serious play for school and not for graduate students".*

The learning outcomes are more difficult to grasp. Despite good overall evaluations, some participants indicate that formats with a high degree of concrete experience and active experimentation are fun (case 1 and 2) but the value of the learning remains unclear or too time consuming to be achieved. An example may explain this line of reasoning: A group of students were trying to build a particular production system (case 1). They had spent more than 25 extra hours additional to their class experimenting in a mind-absent flow and were driven by unnecessarily ambitious plans for a fully automated system, but failed to implement their plan with the available material. They decided to quit the exercise and asked for a final consultation with their supervising tutors in early January 2012. Throughout the consultation the students explored their tendency to over-engineer the system and made up their mind for a much simpler solution in order to complete the course. This was apparently a painful experience for the students since they invested long hours into their first concept. However, the most remarkable quotation during the final presentation was the following.

"The most important learning of this course took place when we failed – to recognize that we were too ambitious and how much it had cost us. That is certainly something useful for the future."

Further evidence for these unintended learning outcomes can be found in an earlier edition of case 1 in 2011. A participant stated:

"I did not learn too much from the game itself. What I learned was the importance of good and organized communication – to do intermediate presentations and define a project plan.
I found it interesting to see how different roles evolved during the project. There were leaders, thinkers, implementers etc. […] not everybody is able to lead a project."

Hence, does this learning prove any value? Fortunately we were able to do a follow up interview in July 2012 with a member of the previously mentioned "over-engineering-group". After participating in the Lego-exercise until February 2012 he had to complete a complex case study concerning facility planning in teamwork from April until July 2012. He suggested the following among several other insights transferred from case 1 to the new task.

"The tendency of getting obsessed with details was resolved; problems were tackled in a more pragmatic manner. Due to strict milestones and central project controlling (and the related pressure) results were always delivered […]."

These insights are certainly some of the basic issues explained in every standard course on project management. However, the self-exposure to a project that is not successful since it lacks these fundamentals seems to provide a suitable alley for students towards really understanding what the course is actually about.

5 Discussion and Conclusion

Finally, we may return to the research questions. The first question asked if different course formats impact students' experience of flow. We conclude a tentative yes:

Active experimentation is a supportive condition to enter the state of flow but it is not a sufficient feature. We found flow also in more abstract and reflective situations.

As to the second question, we conclude that material has an impact on entering the state of flow. Especially the modular structure of physical objects allows for an easy entry into the learning process and provides enough complexity to cope with higher levels of skill and abstraction. However, we observed a notable level of cynicism among some participants, which is at least partly due to utilized material. Other researchers [e.g. 19] observed the same issue and argued that cynicism is due to the blurring of the border between private and professional life. We may add that not every course format suits every student due to different learning styles and it is therefore rather simple to derive from the obvious and have objections against using plastic bricks.

Furthermore, our results suggest that flow is linked to the learning outcome (research question 3). The link is established in a rather unexpected manner since high levels of flow yield learning with a scope different to the intended (case 1). From a learning perspective we see a strong need to further enable participants taking responsibility of their own learning when finding themselves in an environment fostering active experimentation and reflecting. We were lucky to find a striking example were high flow and experience based learning was successfully transferred into a new task. However, such success stories need to be further studied in order to give this opportunity to more students.

Despite all limitations of this study, we see a strong argument for physical objects in industrial engineering education and support for the theory of constructionism. Nonetheless, there is a strong need to further elaborate our findings and to study also combinations of physical and digital "cyber" objects in the future.

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