An Embodied Cognition Approach To Collaborative Engineering Design Activities

Gitte VAN HELDEN
Faculty of Aerospace Engineering, Delft University of Technology, The Netherlands;Leiden Delft Erasmus Centre for Education and Learning, The Netherlands;4TU Centre for Engineering Education, Delft University of Technology, The Netherlands, g.vanhelden@tudelft.nl

Barry ZANDBERGEN
Faculty of Aerospace Engineering, Delft University of Technology, The Netherlands, B.T.C.Zandbergen@tudelft.nl

Anna SHVARTS
Freudenthal Institute for Science and Mathematics Education, Utrecht University, The Netherlands, a.y.shvarts@uu.nl

See next page for additional authors

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G. van Helden [1]
Faculty of Aerospace Engineering, Delft University of Technology
Leiden-Delft-Erasmus Centre for Education and Learning
4TU Centre for Engineering Education
Delft, the Netherlands
0000-0001-6255-1797

B. T. C. Zandbergen
Faculty of Aerospace Engineering, Delft University of Technology
Delft, the Netherlands
0000-0001-6417-952X

A. Y. Shvarts
Freudenthal Institute for Science and Mathematics Education, Utrecht University
Utrecht, the Netherlands
0000-0001-6556-0058

M. M. Specht
Leiden-Delft-Erasmus Centre for Education and Learning
4TU Centre for Engineering Education
Delft, the Netherlands
0000-0002-6086-8480

E. K. A. Gill
Faculty of Aerospace Engineering, Delft University of Technology
Delft, the Netherlands
0000-0001-9728-1002

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[1] *Corresponding Author*

G. van Helden,

g.vanhelden@tudelft.nl

ABSTRACT

Higher educational institutions have broadly adopted Collaborative Engineering Design (CED) activities to prepare students for complex problem-solving in multidisciplinary settings. These activities are non-linear and mediated by various social practices and tools. Therefore educators might struggle in facilitating the achievement of specific learning goals. Embodied cognition is an approach that explains non-linear behaviour through orgamism-environment interactions and might therefore provide educators with insights on how to prompt students towards desired actions in CED activities. According to embodied cognition, we learn through actions that emerge as a response to a problem (task) and environmental constraints. Educators can guide students' behaviour by proposing tasks and adapting the environmental constraints of a learning situation, thus creating a field of promoted action. In this paper, we outline the progress of a design-based research in which insights from embodied cognition are implemented to promote desired student behaviour in CED activities. We report on the results of our problem-exploration phase. A systematic literature review and focus groups with students revealed that students are often hesitant to adopt new practices and tools that could potentially improve their collaborative design process. Next, we propose three theory-based design principles in which the task and environmental constraints are leveraged to foster the adoption of practices and tools and apply them to CED activities. Finally, we will share preliminary observations of the learning processes triggered by the designed activities and outline the directions for future research.

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1 INTRODUCTION

Contemporary challenges require engineers that are able to solve complex engineering problems in a multidisciplinary context (Winberg et al. 2020; Hadgraft and Kolmos 2020). Higher educational institutes often adopt Collaborative Engineering Design (CED) activities to foster the development of technical and non-technical skills desired by industry (Picard et al. 2022; Shuman, Besterfield-Sacre, and McGourty 2005). However, problem-solving processes during CED activities are non-linear and continuously mediated by various social and material resources (Vujovic and Hernandez-Leo 2022). This can make it challenging for educators to facilitate the development of specific learning objectives. Theories on embodied cognition, such as theories on dynamical systems (Shvarts et al. 2021; Guevara, Rojas Ospina, and van Geert 2020), can potentially provide insight into how to guide students towards desired behaviour in non-linear problem solving. A *functional dynamic systems approach* centralizes organism-environment interaction in the learning process. We learn through actions, that emerge as a response to a problem and the affordances and constraints of the environment (Bernstein 1996; Abrahamson and Sánchez-García 2016). Researchers investigated how the design of a task and learning environment can guide students' self-exploration and discovery during problem solving activities in the domains of mathematics (Abrahamson 2013; Shvarts and van Helden 2022) and science (Lindgren et al. 2016; Enyedy et al. 2012). Still, the engineering domain remains underexplored (Weisberg and Newcombe 2017), while it was shown that bodily interactions are central to discovery and meaning making processes during CED activities (Davidsen, Ryberg, and Bernhard 2020; Bernhard et al. 2019).

In this paper, we will report on the progress of a design-based research in which we investigate how a functional dynamic systems approach can be leveraged to foster productive collaborative behaviours, including the use of project management practices and associated tools. Design-based research is a methodological framework in which the design of a learning environment is intertwined with testing and developing theory (Bakker 2018; McKenney and Reeves 2019). It involves the iterative development of solutions to educational problems in real-world contexts, following the reoccuring activities of exploring a problem and available theoreretical perspectives for solving the problem, designing a theory-based solution, testing the solution in a classroom setting, and analysing the results to inform theory and practice. The main contribution of this paper is the design of a theory-based CED activity. We will outline the rationale for the designed solution. Furthermore, we will share preliminary observations from the first classroom experiment and reflect on steps that will be taken in the future

2 PROBLEM EXPLORATION

We have used literature and insights from practice to identify problems that occurred frequently within CED activities. We conducted a systematic literature review on the implementation of collaborative learning in engineering design activities (van Helden et al. 2023). It was found that students were often hesitant to use new tools in CED activities, even when these tools offered functionalities that could potentially improve their collaborative design practices. We encountered a similar problem when analysing a Master-level CED course at the Faculty of Aerospace Engineering, Delft University of Technology (van Helden et al. 2022). During the Collaborative Space Design Project (CSDP), we aimed to teach students new practices for design (e.g. concurrent engineering) and project management (e.g. Scrum). Even more, we offered them an environment, called the Collaborative Design Lab (CDL), which holds a variety of industry-relevant tools that enable new ways to collaboratively design and manage a project. Its most salient features include: 1) Nureva Span Wall (Nureva n.d.), a large digital whiteboard with touch screens for projecting and organizing information, 2) COMET (RHEA Group n.d.), a tool suitable for implementing an integrated design model, 3) and a conferencing tool that allows outsiders to interact with a team in the CDL. When conducting focus groups with students, it was found that they relied on intuitive approaches to design and project management they already knew. They did not use the tools in the CDL, neglecting the role of these tools within the tasks of managing and conducting collaborative design projects. Still, all student teams acknowledged that they could have managed their project in more efficient ways if they had made use of a more structured approach to project management.

3 THEORETICAL PERSPECTIVE

A traditional way to introduce new practices and tools that might assist those practices is through step-by-step tutorials that explain or demonstrate desired behaviour (i.e. we show, you imitate). The assumption is that by structuring and breaking-up content it is easier for students to mentally process the to-be-learned practices. However, from an embodied cognition perspective, researchers have argued that learning new practices and discovering how tools can support these practices cannot be reduced to step-by-step routines, as practices are holistic and emergent processes (Dreyfus 2007). Instead, learning environments should facilitate self-discovery of new practices and the role of tools in them through action (Abrahamson and Sánchez-García 2016; Shvarts et al. 2021). Let us illustrate this with the example of a child learning to eat with a spoon. This new practice is not learned through a step-by-step breakdown of what the child should be doing but through enactment. It starts with a need to perform a certain action which can be as simple as the child being hungry and wanting to eat. The amount of actions relevant for solving this problem is restricted by the task at hand. When eating a plate of rice, the child could rely on actions she can already perform: eating with her hands. However, if we change rice for a bowl of soup it will no longer be possible to use her hands for eating. The child is pushed towards finding other ways of bringing the food to her mouth such as using the spoon in front of her. Still, it can be that the child is not yet capable of immediately using the spoon to fulfill the task. In this case, the environment can be altered to facilitate the self-discovery of new practices. For example, the regular spoon can be replaced with a children's spoon that has a handle with finger grips, to make it easier and more inviting to hold the spoon. The task and environment guide the child towards performing new actions and thus expanding her action possibilities. Initially, theories on embodied cognition explained only learning at a motor level, such as learning to eat with a spoon. However, researchers expand those theories and create embodied learning materials in which the task and environment guided students when learning seemingly less tangible content, such as mathematical (Abrahamson 2013; Shvarts and van Helden 2022) and scientific (Lindgren et al. 2016; Enyedy et al. 2012) concepts. An important difference between learning to eat with a spoon and learning, for example, mathematics, is that for mathematics we also want the child to describe and explain what she is doing. In the current study, we will build on this work and expand toward a new problem that is essential to CED: how to manage a project.

4 DESIGN OF PROBLEM SOLUTION

In this section, we will describe the rationale and the design of our learning activities aimed at fostering students' adoption of Scrum as a project management practice and the use of associated tools. In section 4.1 we describe the selected learning content. In section 4.2, we will introduce three Design Principles (DP) derived from literature on embodied cognition. In section 4.3., the designed activities will be described and linked to the DPs. Furthermore, we will introduce our Hypothetical Learning Trajectory

(HTL) (Bakker 2018), which is the analytical instrument for evaluating the designed activities.

4.1 Learning content: Scrum and tools

Managing complex projects is an important skill for engineering students [source]. We suggest “re-inventing” Scrum (Schwaber and Sutherland 2020) as a useful approach to learning project management. Scrum is a widely adopted agile approach to project management, existing of three reoccurring phases: 1) forethought, 2) execution and monitoring, and 3) reflecting. The forethought phase concerns project planning and starts with translating customer requirements into tasks. The overview of all tasks for the project is called a project backlog. There are too many tasks in the project backlog to be tackled at once, so they will be divided over multiple sprints. At the beginning of each sprint, tasks from the project backlog are selected. To create an attainable sprint planning, it is important to roughly estimate the duration of each task, prioritize tasks, and formulate the “ definition of done” (i.e. when a task is finished). During the execution and monitoring phase, the team works autonomously on the tasks from the sprint backlog. To continuously monitor the progress, a Scrum board is used. This is a board displaying the tasks from the sprint backlog and their status: “open”, “in progress”, or “done”. In addition to this, every day starts with a short daily Scrum meeting, in which all team members give an update on the status of their intended tasks. At the end of the sprint, it is time for the reflection phase. In Scrum, there are two types of reflection. First, there is the sprint review, in which the team evaluates their product with their customer and revises the project backlog. Second, the sprint retrospective, aimed at reflection on the collaborative process, is an occasion in which all team members can provide suggestions to optimize the Scrum process. After finalizing the reflection phase, a new sprint can be planned and the cycle starts again.

In the CDL there are tools available to support the Scrum process. The most important tool is the Nureva Span Wall: a large digital whiteboard with touch screen. This wall can be used as a shared visual point of reference during the three phases of the Scrum process. There are plenty of software tools available for project management. However, in this study we aim for students to self-discover Scrum as a response to the problems they face during our workshop. For example, we want them to think about what they would like to monitor and what structure would support this. In other words, we want them to invent their own Scrum board, rather than use a given structure. For this purpose, we decided to introduce Miro(Miro n.d.), which is a software tool that provides a blank canvas on which team members can create and structure content.

4.2 Design principles and hypothetical learning trajectory

For the design of our learning activity, we drew on theories of embodied cognition. Specifically, we focused on a functional dynamic system approach, as this theory explains how new tools become incorporated into learners’ practices through organism-environment interactions (Shvarts et al. 2021). Following this approach, action is regulated by a functional body-brain system, which is a non-centrally organized system that shows non-linear yet stable behaviour within the constraints of the environment (Guevara, Rojas Ospina, and van Geert 2020).

DP 1: creating a field of promoted action – from problem to action. Following a functional dynamic systems approach, action is central to learning (Shvarts et al. 2021). In this context, action is not a synonym for movement, as actions always emerge as a response to a problem (Bernstein 1996). Actions are thus characterized by the *intentionality* to reach a certain target state. While performing an action, we are continuously interacting with our environment, which holds certain *affordances* (i.e. opportunities for action) (Gibson 1979) but also *constrains* the actions that can be performed. Learning takes place when a task (i.e. problem) and the environment guide us towards performing new actions -- think of the example of the child learning to eat with a spoon. Learning can be supported by narrowing available action possibilities and creating an environment in which students are guided toward performing new (desired) actions: *a field of promoted action*.

DP 2: reflection on action – from naïve to formal. Students perform various actions in order to solve a problem. To connect these new behaviours with formal practices, actions need to be re-described verbally. When prompting students to reflect on their actions, the reflections that emerge are often naïve. An educator can play an essential role in helping students to refine their perspective toward the culturally accepted terminology and inscriptions (Vygotsky 1978; Flood 2018).

DP 3: facilitate transfer – from learning situation to new situation. When educating, we typically aim for students to develop behaviours that transcend the learning situation and are also used in novel situations. This phenomenon, also known as transfer of learning, emerges when a student *recognizes* an affordance for action from the learning situation in a new situation (Greeno, Smith, and Moore 1993; Shvarts and van Helden 2022). We can support students' noticing of invariance between a learning situation and a new situation, by creating similarities between the constraints of the task they need to fulfill and the environment in which they operate.

4.3 Design of learning activities

We will now describe the design of our learning activity, and explain how each of our DPs is integrated. We designed two workshops on Scrum, one forethought and monitoring and one on reflection, that can be implemented in CED courses. In our workshops, we do not provide students with a breakdown of Scrum in advance. In line with DP 1, we give them *tasks* that contain one or more *problems* that can be solved by problem management practices. For example, the first task about planning is to create an overview of what needs to be done before completing the project. For completing this task, multiple problems need to be solved that are all connected to key elements of Scrum, including: 1) knowing which tasks need to be solved (project backlog), 2) which tasks need to be solved first (prioritizing tasks), and 3) if solving these tasks is attainable in the given amount of time (estimating tasks). We expect this will elicit an intentionality to so solve the problem at hand. While doing so, we expect students to use *artifacts* that are available in the environment, including the Nureva

Span Wall and the Miro canvas. Following DP 1, we also introduced environmental constraints to guide students' behaviour. For example, we do not provide a blank Miro Canvas. Rather, we have created virtual artifacts that will help to elicit desired behaviour, such as "working areas" to centrally collect tasks for the project backlog and sprint backlog and "text boxes" to write down tasks (Appendix A). These artifacts do not impose a structure on students, rather they are building blocks for a structure that might emerge for the students when performing desired actions. We implemented DP2, by asking students to reflect on the actions they performed at the end of the workshop. We ask students to construct a timeline in Miro in which they list the actions they performed. To refine their perspective toward the culturally held view, the educator presents them with "sticky notes" with Scrum terminology in Miro and asks them to map the Scrum terms to their own timeline. Finally, we implemented DP 3 by creating continuity between the task and environmental constraints of the Scrum workshops and the design sessions. An example related to the task is that students will have time pressure to deliver their design, as we believe this will sustain the need to estimate the duration of tasks after the workshops. With regard to the environment, we will, for example, turn on the Nureva Span Wall during students' first design session, so that they will be guided into using the wall during their planning activities.

4.4 Hypothetical Learning Trajectory

To investigate whether desired actions were triggered by the designed activities, we created an HTL, which is an analytical instrument that connects a learning task to expected observable behaviour. For illustration, a fragment of our HTL is shown in Table 1. In this HTL, we have outlined the *workshop tasks* (column 2), the *intentionality* (column 3), the *problems* students have to solve to complete a task (column 1), and the *constraints* of the environment used to guide them toward desired behaviour (column 4). For each problem, we have outlined the behaviour that is expected to emerge during the workshop and stabilize during the design sessions (column 5). Next to this, we have connected each problem to a formal Scrum concept (column 6) and to task and environmental constraints that should facilitate transfer during the design sessions (column 7).

5 CLASSROOM OBSERVATIONS

We have implemented the workshops as described in the HTL within the CSDP. In this course, teams of seven to nine students collaboratively design a solution to a complex and open-ended engineering problem. Over a period of eight weeks, students have weekly co-located design sessions in the CDL. The workshops on Scrum took place in the first two weeks of the course. Our goal was to elicit the practices that were outlined in the HTL during the workshops (learning situation) and the design sessions (transfer situation). Two out of six student teams participated in our study.

Table 1. Fragment of HTL. (DP 1 = blue; DP 2 = green, DP 3 = orange)

Problem	Workshop task	Intentionality	Environmental constraints	Expected stabilized behaviour	SCRUM concepts	Transfer to design sessior
How does everyone know what tasks should be done?	Create an overview of what needs to be done for your project, based on the conversation you had today with your project coach.	Collective overview of tasks are needed to finish project and why this task needs to be fulfilled.	Used artifacts: Nureva Span Wall, Miro board Environmental constraints: in Miro "working area" that can be used to collect tasks for project backlog and "text boxes" that can be used to write down tasks and move them to project backlog.	1) A "working area" in Miro is selected, that will be used as a space to collect tasks for the product backlog; 2) Mention task that should be fulfilled before project completion; 3) Mention what the added value (increment) is of this task for the customer; 4) Write down tasks and increment in "text-box" in Miro and put task in project backlog; 4) repeat 2 and 3.	"Creating a project backlog" "increment"	*Environmental.* When students enter the CDL, the Nureva Span Wall will be opened, and their self-made Miro Template i shown *Task:* Customer requests a project plan
How does the team know which tasks should be done first?		Collective overview of what is the order in which tasks should be done.	Used artifacts: Nureva Span Wall, Miro board Environmental constraints: in Miro different "visual markers" including text, numbers, colours.	1) Discuss order of tasks 2) Create or use existing "visual markers" to represent relative priority of each task (e.g. numbers, or change of visual order)	"Prioritize items"	*Task:* Customer requests a project plan
How does the team know if the task list is attainable?		Collective overview of duration of tasks.	Used artifacts: Nureva Span Wall, Miro board Environmental constraints: in Miro different "visual markers" including text, numbers, colours.	1) Discuss rough duration of tasks 2) Create or use existing "visual markers" that represent relative duration of each task (e.g. order or colours that reflect duration)	"Estimate items"	*Task:* Time pressure
From naïve to formal	Individually create a timeline of the actions you have taken to solve the workshop tasks.					
	Merge your individual timelines to one big common timeline, that reflects the actions you have taken as a team to solve the workshop tasks. You have worked on the Miro board, and a structure has emerged. Create a template for this structure in Miro that can be used by another group. Now connect these templates to the timeline. Educator gives students sticky notes with scrum concepts (column 6) on them. Students are asked map these concepts to their template and timeline. Which are similar? Which are not yet covered? Which extra rules have they came up with, that are not part of the scrum sequence?					

Preliminary observation revealed that these student teams showed much of the expected behaviours during the workshops, including creating a project backlog with an overview of tasks, selecting a sub-set of tasks for the sprint backlog, and reflecting on the collaborative process. However, not all desired behaviours were shown during the workshops. For example, we students did not come up with a Scrum board that could be used to monitor complex problems.

6 CONCLUSIONS AND FUTURE WORK

In this paper, we have showcased the progress of our design-based research. We first introduced a problem found in literature and practice: students are often hesitant to adopt new practices and associated tools during CED activities. Next, we presented the design of a learning solution, based on insights from embodied cognition. Preliminary observations revealed promising results, however, also revealed that not all desired behaviors could be observed during the workshop. The next step is to conduct a thorough analysis of the classroom implementation described in the previous section. During this implementation, we gathered audio and video data that will be qualitatively analysed to investigate whether expected stabilized behaviours, as described in the HLT, emerged during the workshop and design sessions. Based on the conclusions derived from this analysis, the DP's and HTL will be revised and again evaluated in a classroom context. Even more, we aim to expand our intervention to new tools and practices, such as the use of concurrent engineering practices and the use of tools for implementing a model of a system or process wherein all specialisms together contribute to creating a design, i.e. an integrated design model.

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APPENDIX A – EXAMPLE OF ENVIRONMENTAL CONSTRAINTS IN MIRO CANVAS