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Mathematical modelling and activation – a study on a large class, a project-based task and students' flow

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We studied how engineering students in a large class (n=346) can be activated by a project-based task, in which they have to model mathematically the motion of an object. The students had to throw an object, use (1) their smart phones for filming, and (2) tracker software for capturing the motion. Through a poster, they had to report their video analysis. We framed activation through the concept of flow, which is a state of being fully absorbed by an activity. We administered a web-based questionnaire (response rate 69%). The results show that such a project-based task is feasible with >300 students and activated them: three out of five experienced flow. Also, we validated the theory that for experiencing flow, a task must be perceived as challenging and that one's skills should match that challenge.

Keywords: flow, large class, mathematical modelling, mathematics for engineers, novel approaches to teaching, project-based tasks.

INTRODUCTION

Harris et al. (2015) studied engineering students' values regarding mathematics finding that not many first-year engineering students have a positive stance towards mathematics. The students see mathematics as a hurdle in their studies, and they are disappointed by the mathematical demands in the first year of their studies. Some even indicate that they wouldn't have chosen the engineering direction if they had known about the mathematics demands before. Nevertheless, mathematics needs to be part of engineering studies, because alumni from engineering studies, such as engineers, managers, researchers, etc., need mathematical modelling competencies to describe, analyse, and predict phenomena to solve problems at the workplace (Alpers et al., 2013). This means, that in particular mathematical modelling needs to be included in engineering studies. It can be integral part of the mathematics curriculum, but the learning of mathematical modelling can also take place in other disciplines, such as physics, where mathematical models are used to describe and analyse physical phenomena. The study described in this paper centres on a mathematical modelling task situated within kinematics (the physics of movement).

In university first-year studies, engineering students often attend large-scale lectures and have tutorial sessions to practice examination-like exercises. However, research has demonstrated the advantages of activating, inquiry-based tasks over these traditional instruction methods (De Jong, Linn, & Zacharia, 2013; Freeman, et al. 2014). This means that we need research in engineering education into what mathematical modelling tasks can be activating, how these can be organised, how

students experience these tasks, what task characteristics create challenges, etc. Moreover, studies with large groups are scarce; the review by Freeman et al. (2014) shows that most studies on students' activation are carried out with small or medium size classes (up to 110 students). With more than 300 first-year students, we can add to the research on how engineering students in large classes can be activated.

Sullivan et al. (2011) describe *challenging tasks* as requiring students to: plan their approach, especially sequencing more than one step; process multiple pieces of information, with an expectation that they make connections between those pieces, and see concepts in new ways; choose their own strategies, goals, and level of accessing the task; spend time on the task and record their reasoning; explain their strategies and justify their thinking to the teacher and other students. We used a task format that fits this description: a *project-based task*, which is a task that cannot be completed within limited time, which has a clear, but not straight-forward goal, there are various approaches to tackle it, and results must be presented through a product, such as a written report or an oral presentation (Blomhøj & Kjeldsen, 2006).

THE TRACKER PROJECT TASK

Domínguez et al. (2015) did research with a group of 20 engineering students and asked them: *a child is throwing a candy to another; make a mathematical model of this movement*. This modelling task is an open-ended task with characteristics of 'a challenging' task (Sullivan et al., 2011): students need to sequence more than one step; process multiple pieces of information and connect the throwing and the model; choose their own strategies, goals, and level of accessing the task; spend time on the task. We adapted the task in the following way: (1) students could choose whatever movement of whatever object: throwing a ball, jumping their skate board, etc.; (2) students were asked to use their *smart phones* for filming, as nearly all students nowadays have smart phones with high quality cameras; (3) students were asked to download *tracker* software (<http://physlets.org/tracker/>), which captures motion in videos based on contrasts and yields a table of time and position coordinates (measurements). We made a tutorial video on the use of Tracker. The measurements were to be mathematically modelled (i.e. create a formula that approximates the movement). The required, final product was a poster, in which students presented their reasoning – another characteristic of a 'challenging task' (Sullivan et al., 2011). The poster had to contain the video analysis, including a discussion of the accuracy of their mathematical model in comparison to the measurements. The task had to be done in groups of two or three. Collaboration was convenient, because one student alone cannot throw and film simultaneously. In our communication with the students we indicated the task as *the Tracker Project*.

It was our first time to implement a project-based mathematical modelling task with such a large group. Unlike earlier studies (e.g. Domínguez et al., 2015) we did neither have a group of 20 students, nor uniform equipment, nor sufficient staff. We couldn't learn from earlier experiences, as – to our knowledge – there are no reports of similar

studies carried out with more than 300 students. The few studies on the activation of students in large classes centre on using clickers in lectures (Freeman et al., 2014). Thus, we didn't immediately want to focus on students' learning, but instead, first study the feasibility of such a task with such a large group, with the variation of cameras, and with students who have little experience with open-ended tasks. We felt that we – as lecturers – should first take the opportunity to learn how it worked in practice, whether students liked the task and how they engaged with it.

In this paper, we report on our research into the extent to which students' were activated by the modelling task. By activation, we mean – for the time being – that the task grasped them and that they liked working on it. Thus, our study is on students' attitudes, which is an aspect of their *affect*. Based on Harris et al. (2015), we expected the engineering students to have preconceived beliefs about mathematics, and we wanted to avoid that our research would be contaminated by their biases. Therefore, we undertook our research by limiting the use of the word mathematics in our communication with students. Abundant use of the term mathematics could trigger memories and bias of traditional mathematics education, which could interfere with their evaluation of the Tracker Project Task.

THEORETICAL FRAME

Recent research in the field of mathematics education and affect conceptualize the latter in terms of complex, dynamic systems and participatory environments (Pepin & Roesken-Winter, 2015). However, while distinguishing between aspects of affect (values, emotions, beliefs, attitudes, etc.), these researchers don't differentiate between aspects of mathematics education. Yet, mathematics education contains many aspects, such as instruction formats, teacher attitudes, tasks, etc. These become invisible when researchers address mathematics holistically and ask students to mark their (dis-)agreement to statements such as: 'mathematics is my favourite subject'. (Dis-)agreement to such a statement gives little room for nuances and contexts. A student partly agreeing with this item might rather have said: "mathematics with this particular teacher is my favourite subject, but last year it was the opposite" or "mathematics could be favourite, if it had relevance for my future".

We wanted to study students' affect through an activity that differed from standard activities within traditional mathematics education. Thus, we sought an activity-based conceptualisation of affect. An activity-based perspective in mathematics education aligns with a socio-cultural perspective. One of its promoters, Lerman (2000), describes mathematics as a socio-cultural practice embedded within a community. Within a school institution, mathematics is a practice embedded in a community of a teacher and a group of students, its rules, language, etc. The activities consist, among others, of explanations by the teacher, and work on tasks by students. This practice differs markedly from mathematics as a practice within a research community, whereby the actors organize mathematical patterns, solve creatively a non-routine problem by using mathematics, and actors may reach different answers. Describing

mathematics socio-culturally as a practice embedded within a community entails focusing on the activities undertaken by the actors, which are mediated by language, tools, etc. Using an activity-based conceptualisation of mathematics enabled us to relate affect to distinct activities and not to mathematics holistically, whereby we could distinguish mathematical activities as having different contexts. In our study the activity was guided by the Tracker Project Task and students had to use mathematics within a kinematics context.

We sought an activity-based conceptualisation of students' affect with respect to them being activated. Activation is an aspect of attitude, just like boredom or anxiety (Pepin & Roesken-Winter, 2015). For this conceptualisation, we turned to a concept, which describes "a state in which people are so involved in an activity that nothing else seems to matter; the experience is so enjoyable that people will continue to do it even at great cost, for the sheer sake of doing it" (Csíkszentmihályi, 1990, p.4). Nakamura and Csíkszentmihályi (2009) describe how they observed rock climbers, gamers, painters and researchers during their challenge, and how these people got absorbed in their activities, felt happiness, forgot about time and basic needs (eating, resting), and were intrinsically motivated (motivated by the activity itself, not by an external incentive). They coined this state: *flow*.

Flow is an activity-based concept: without activity, there cannot be an experience of *flow*. *Flow* is an experience of an individual, yet, the activity is culturally embedded (e.g. gamers play a game created by others, painters expose their work). In fact, social activities can intensify *flow* through group cohesion (*group flow*). We will use students' self-reported experience of *flow* as an operationalisation of their activation through the Tracker Project task. *Flow* has also been studied in mathematics education (a.o. Armstrong, 2008; Drakes, 2012; Liljedahl, 2016), observing that many students in traditional mathematics classes is to not experience *flow* at all.

Figure 1 (left) illustrates how *flow* depends on the perceived challenge of a task and perceived skills of a person engaging in the task (Nakamura & Csíkszentmihályi, 2009). If the activity is too challenging for the skills, then the task may cause anxiety. If the activity is too easy for the skills, then the task may cause boredom. When challenge and skills match, a person engaging in a task may experience *flow*. In later work, Csíkszentmihályi and colleagues adapted the diagram, adding more affective states, and stating that *flow* can be only experienced when a participant perceives the task as more than averagely challenging, and that he/she thinks to have the skills that match this challenge, see Figure 1 (right). The older diagram still appears in recent studies (e.g. Liljedahl, 2016). Therefore, we opted to use our study to empirically validate the old versus the new theory and see whether flow occurs only when the actor perceives a more than average challenge. Our research was guided by two questions. The first was empirical: To what extent did the Tracker Project Task make students experience *flow*? The second was about the choice of flow diagram: Can

one of the Csíkszentmihályi diagrams of *flow* be confirmed by plotting skills, challenge, and *flow* into one diagram?

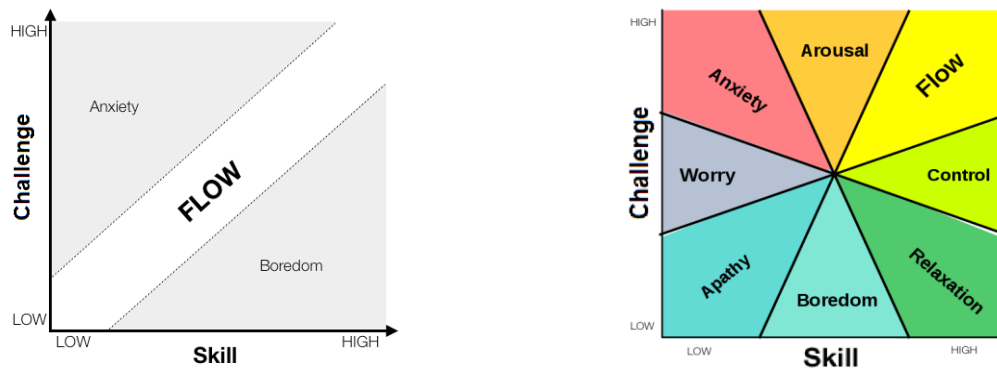


Figure 1: *Flow* and other affective states related to task challenge and a person's skills (adapted from Nakamura & Csikszentmihalyi, 2009)

METHODS

In the Spring of 2017 we offered the Tracker Project task to all first-year students in engineering at our university (Mechatronics, Electrical Eng., Data Eng., Renewable Energy, ICT). There were 346 students for whom the task was mandatory.

The research design for studying students' activation in terms of *flow* was a survey. We collected data through a digital questionnaire. Participation in the survey was voluntary, but encouraged with prizes of NOK 500 (approx \$50) for three randomly drawn participants. After removing seven participants (four had constantly chosen a 3 as answer, three were 2nd-year students for whom the task wasn't mandatory), we had n=239 students. This response rate of 69% is very high (Bryman, 2015).

Based on instruments from earlier research (Armstrong, 2008; Egbert, 2004), we developed 15 items in alignment with the task. Each item consisted of a statement, asking students for their (dis-)agreement on a 5-point Likert scale, from 1 (strongly disagree) to 5 (strongly agree), see the Appendix. Five items were designed to measure students' perception of *flow*. For this, they could indicate, for example, whether they forgot about the time, and whether they even would do the task if it wasn't obligatory. By having several items related to *flow*, a participant's score is indicator of the extent to which he/she had experienced *flow*. Five other items were designed to measure students' self-perceived *skills* (e.g. 'the Tracker technology was easy to use' or (inverted) 'It was complicated to find the right formula of the model'). And a further five items were designed to measure students' perception of the task's *challenge* (e.g. 'during this task I started thinking about other movements (what if..?)' and (inverted) 'this task was more for secondary schools').

We make a difference between *flow* as a concept (written in italics), and the scale of Flow (with a capital letter). The concept of *flow* is a psychological state of a person, and therefore it cannot be measured. However, we assume that it can be approximated by a score on the scale of Flow. A student's score on this scale results from his/her

answers to the five questions in our questionnaire. The score on the Flow scale is calculated by adding the scores on the five questions. As the score on one question ranges from 1–5, the score on the Flow scale ranges from 5–25. Likewise for respectively, *challenge* and the Challenge scale, and *skills* and the Skills scale. To increase reliability, within each scale one or two questions were inversely posed, and the scoring was inverted, too. As measure of reliability (internal consistency), we calculated Cronbach’s Alpha: the Skill scale yielded 0.55, the Challenge scale yielded 0.73, and the Flow scale yielded 0.63. A scale is considered unreliable if Cronbach’s Alpha is less than 0.5 (Bryman, 2015). Thus, the three scales can be considered as being reliable.

RESULTS

We observed students everywhere on campus, flying paper helicopters, riding skateboards, or throwing apples, cats or balls. We received more than 100 posters in our Virtual Learning System. As explained before, in this study we didn’t want to focus on students’ performance (the precision of their measurements, their understanding of modelling, the depth of their analysis, etc.). Instead, we focused on the feasibility of an activating tasks for massive students groups, which would show in their activation in terms of *flow* as measured through the questionnaire. Second, we aimed at seeing whether the measurement reproduced one of the two flow diagrams. The Appendix shows mean scores on all items.

The mean score on four items in the Flow scale is higher than 3.5, being well on the positive side. This indicates that a majority of the students experienced a state of *flow* to quite an extent, in particular with respect to losing track of time, and not being easily distracted. Only item 14 was answered below the middle range. This item focuses on doing the task even if at some costs (Csíkszentmihályi, 1990), which translates in our study to: one out of four would even do the task voluntarily.

Scale	mean (std dev)
Flow (5 items)	17.0 (3.1)
Challenge (5 items)	15.5 (3.3)
Skills (5 items)	18.8 (2.7)

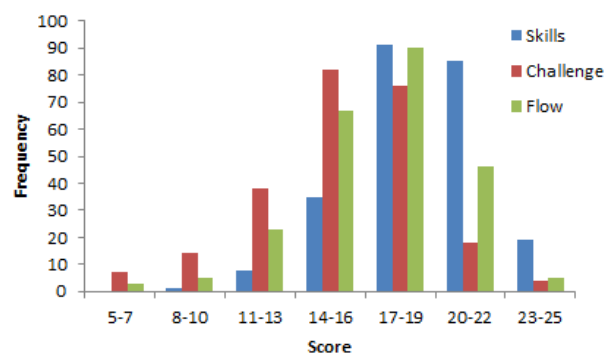


Figure 2: Scores to Skills, Challenge, and Flow scales (n=239)

When adding the students’ scores on the five questions, we obtain their score on the scale Flow. See Figure 2 (right) for a bar graph. This graph shows the frequencies of scores (number of students with certain scores). The green bars of the Flow scale show a skewed distribution. On this Flow scale, 31 students (13%) scored 13 points or lower, 67 students (28%) scored in the middle range of 14–16 points, and 141

students (59%) scored 17 points or higher. When we take 17 points as a threshold, then three out of five students experienced *flow* to quite an extent. The table in Figure 2 presents mean scores on the scales for Skills, Challenge and Flow (minimal score = 5, middle score range = 14–16, maximal score = 25). The scores on Skills are highest: generally, students perceived themselves as highly skilled; the low standard deviation indicates a high agreement among students. The scores on Challenge are around the middle range; these scores are most “normal” (making a Gauss curve).

To validate the Csíkszentmihályi diagrams (Figure 1), we created a scatter diagram. Each student was represented by a dot defined by his/her Skills score on the x-axis and his/her Challenge score on the y-axis, see Figure 2. The resulting diagram shows a scattered distribution, which means that there is no correlation at all between the scales Challenge and Skills ($r = 0.097$). In this diagram, we added the third scale, the one for Flow, by colouring the dots depending on the student’s Flow scores. These scores range from red to orange (13 or lower), via yellow (middle range, 14–16) to green (17 or higher). Roughly, one can discern overlapping red, yellow and green areas. The red area is more visible at the bottom showing the students who experienced little *flow* (13% of the students). These students indicated that the task posed little challenge, independently of their perceived skills. The yellow area runs from bottom right to the centre showing the students who experienced medium *flow* (28% of the students). These students either indicated low challenge and high skills, or medium challenge and medium skills. The green area is the largest with the majority of students (59%). It is in the top-right, fading towards the centre, showing the students who experienced *flow* to quite an extent. These students indicated that they perceived the task as challenging, and they perceived themselves skilled.

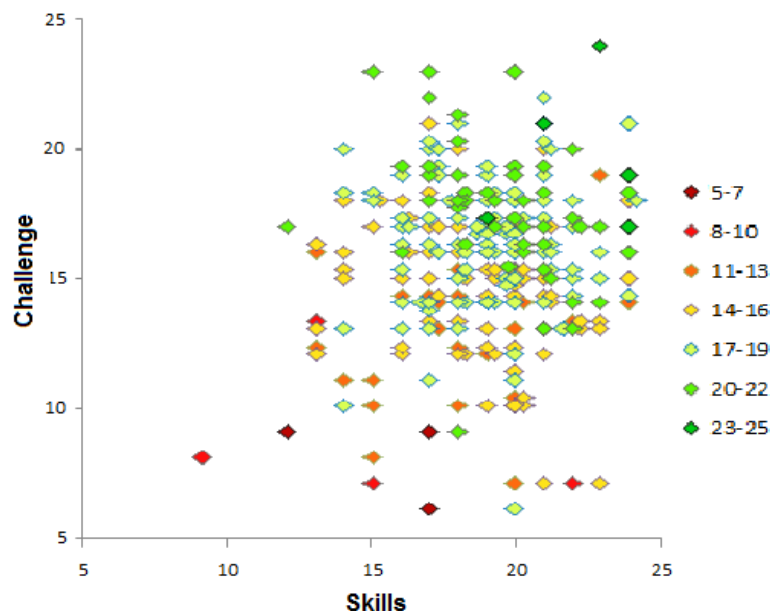


Figure 3: Flow score indicated by color, as depending on Skills and Challenge

This colour distribution of Flow does not confirm the earlier Csíkszentmihályi diagram (Fig 1, left), as the green dots do not centre on the diagonal. Instead, the

green dots are more to be found in the area where the later Csíkszentmihályi diagram (Fig 1, right) situates *flow*: the task must be perceived as quite challenging, and this challenge must match one's skills. A majority of the students in our study indicate that they perceived the Tracker Project Task as such.

In light of the different regions in the later Csíkszentmihályi diagram, we also see many students who may fit into the affective states of 'control', 'arousal' and 'relaxation'. Only few students may fit the more negative affective states of 'apathy', 'boredom', 'anxiety' and 'worry'.

CONCLUSION, DISCUSSION, RECOMMENDATIONS

We studied whether a project-based task was feasible with a class of more than 300 students, that is: whether the task activated individual students. The first research question asked: to what extent does the Tracker Project Task make students experience *flow*? The results from the survey showed that a majority of the students (59%) experienced *flow* to quite an extent, forgot about time and wanted more of such activities. This result was confirmed by anecdotal evidence of their boasting stories in the tutorials of them throwing objects, and the high response rate to the survey. This means that the Tracker Project Task activated a majority of the students and that they had positive attitudes towards it. Thus, an activating mathematics task can be feasible with a large class of engineering students, even if they are known to have a negative stance towards mathematics (Harris et al., 2015).

The Tracker Project Task was designed to be challenging with characteristics such as: expecting students to process multiple pieces of information, that they make connections between those pieces, choose their own strategies, and explain their strategies to others (Blomhøj & Kjeldsen, 2006; Sullivan et al., 2001). We observed other characteristics in the Tracker Project Task that activated the students. First, the task had a clear goal, which was understandable to all students. We observed this through the few questions that we got from the students on how to carry out the task. Thus, the task was easily accessible, also known as *having a low floor*. Second, the better students were able to challenge themselves further, allowing for *a high ceiling*. Third, the use of readily-available technology (cameras in smart phones, tracker software) may have captivated the engineering students, who are known to be technology minded. Fourth, the task was a mathematical modelling task embedded in engineering practices, whereby mathematics served non-mathematical purposes; this showed students the relevance of mathematics to their studies, and contrasted with bare mathematics tasks that alienate and demotivate students.

Our second research question pertained to the theory of *flow* and how it can be conceptualized in a diagram (Nakamura & Csíkszentmihályi, 2009). Our data reject the earlier theory that *flow* depends on the alignment of skills and challenge. Instead, our data support the later theory that *flow* occurs when the participants perceive the task more than average challenging, and that their skills should match this challenge.

Furthermore, we take from our study that the concept of *flow* proved useful for activity-based research on affect in mathematics education.

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APPENDIX

Mean scores on all items (1=lowest, 3=middle, 5=highest).

Flow questions	mean (std dev)
(Inv) This Tracker task took too much of my time	3.67 (0.88)
Time was flying when we worked in this task.	3.40 (0.92)
(Inv) I was easily distracted when we worked on this task.	3.55 (0.91)
I would do this task even if it wasn't obligatory.	2.60 (1.13)
I would like to have more of such practical tasks.	3.70 (1.02)

Skills questions	mean (std dev)
The Tracker technology was easy to use.	3.89 (0.88)
(Inv) It was complicated to find the right formula of the model.	3.38 (0.92)
The aims of the task were clear to me.	3.96 (0.91)
During this task I had full control over what we did.	3.77 (1.13)
Filming the movement of an object was easy.	3.76 (1.02)

Challenge questions	mean (std dev)
This "Modelling med Tracker" task made me curious.	3.61 (0.75)
Making a poster made me feel like a "real scientist".	2.52 (1.03)
(Inv) This task is more suitable for secondary schools.	2.58 (0.95)
This task helped me to better understand the theory.	3.39 (0.88)
During this task I started thinking about modelling other movements (what if..?).	3.31 (1.12)