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4 Collaboration and Co-regulation in Invention Projects

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Introduction

Long-term collaborative work requires students' commitment to coordinated problem-solving, the development of a shared object, and the division of labor to support their collaborative work (Barron, 2003; Järvenoja & Järvelä, 2009; Riikonen et al., 2020).

When developing invention pedagogy, it is essential to understand how students collaborate in teams when pursuing open-ended and emergent invention challenges. It also means understanding how to support the learning of all students according to the principles of inclusive education (United Nations Educational, Scientific, and Cultural Organization [UNESCO], 2016). One of the general aims of Finnish education is to foster socially sustainable inclusive education and thus eliminate the exclusion that might reduce students' social relationships (e.g., Honkasilta et al., 2019). It means an increased risk of reducing options for students with special educational needs (SEN) to follow their educational aspirations and citizenship skills in education.

The invention challenges, which are completely beyond students' capabilities, may be experienced by SEN students as challenging. However, little is known about how students with diverse capabilities have been able to participate in long-term collaborative invention projects. Previous research indicates that learning methods in which knowledge is built collaboratively in iterative cycles and through working with real-life challenges are of benefit to all students' learning (McGinnis & Kahn, 2014). However, such diversity of academic knowledge and learning skills might have a negative influence, especially on SEN students' active participation in collaborative groups (e.g., Anderson et al., 2008; Cohen, 1994). Through the case examples, we will examine the level of socially shared regulation in invention teams in which students with or without SEN collaborate. From the perspective of successful invention projects, the extent to which students are taking other team members into account and how they are mutually carrying out the responsibilities for achieving common goals is critical (Barron, 2003; Damşa et al., 2010; Pijl & Frostad, 2010). We examine collaboration and social regulation as an activity in which students jointly regulate their design and making activities as a team in relation to attaining a shared object.

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Teachers see students' participation in the social regulation of invention activities and their pursuit of the joint object with a flexible division of labor as active involvement, which also engages SEN students in learning (Sormunen et al., 2020). Students are engaged in co-designing their knowledge-creating inquiries and deliberately organize team processes to maintain a shared understanding of the unfolding process and evaluate their progress toward the shared invention (Dillenbourg, 1999; Miyake & Kirschner, 2014). We focus especially on the development of small group learning and the shared regulation of collaborative activities. In this chapter, we will introduce two invention projects that we organized. Both cases focus on the inclusive class settings typical of today, and we spotlight invention teams in which students with or without SEN collaborate. We seek to deepen the current knowledge on the emergence and flow of collaboration in longitudinal invention projects; the principles and findings addressed are adaptable for all learning by making environments.

Invention Projects Require Object-Centered Social Interaction

Our investigations engaged teams of students in pursuing invention projects and ideating, designing, and making artifacts. Collaboration within student teams has been investigated rigorously, especially in relation to collaborative talk and action (e.g., Barron, 2003; Buchholz et al., 2014). In many cases, collaboration is studied intensively in the field of design and technology education (Hennessy & Murphy, 1999; Kangas et al., 2013; Rowell, 2002). The invention projects represent nonlinear knowledge-creating learning processes, through which teams of students are engaged in long-standing collaborative efforts of solving an open-ended challenge and pursuing emergent epistemic objects such as ideas, visions, and artifacts in making. The co-regulation processes involved in virtual settings of technology-mediated learning have attracted the interest of many investigators (Järvelä & Hadwin, 2013). However, invention projects diverge from traditional computer-supported collaborative learning (CSCL) in terms of being embedded in a shared physical maker space (e.g., a craft classroom). Our data involve the video recording of collaborative interaction by student teams *around* digital fabrication tools and instruments instead of interaction *through* virtual learning environments (Riikonen et al., 2020); this makes the social regulation of maker activity less problematic.

Yet, invention projects may involve overwhelming challenges for all team members due to working with unfamiliar digital fabrication technologies, encountering unanticipated construction problems, and carrying out inquiries leading to unforeseen directions (Gutwill et al., 2015). Such projects create unique learning situations as students struggle with joint efforts of finding solutions, achieving goals, sharing experiences and knowledge, and having a sense of making a creative contribution. Participating in a collaborative group alone can be challenging for struggling students, especially SEN students. Participants must negotiate between various invention ideas, available tools and technologies, and constraints inherent in designing and making (Petrich et al., 2013). If a student feels that they are not a productive member of the team, it will affect their cognition and behavior, leading them to withdraw from the work (Anderson et al., 2008; Cohen, 1994). Instead, if a student feels accepted by peers, they may dare to express opinions and participate in negotiations and joint decision-making (Jordan & McDaniel Jr., 2014; Pijl & Frostad, 2010). To address an invention challenge successfully, a team must simultaneously deal with epistemic and technological challenges as well as organize, in real time, their ongoing design and making processes (Mehto et al., 2020; Riikonen et al., 2020).

The students' collaboration requires the team members to focus on a shared epistemic object, that is, an artifact-in-making that they need to build together during the invention process (Mehto et al., 2020). The success of collaborative teamwork is critically dependent on students who actively engage in and take responsibility for the learning process. To ensure student collaboration in inclusive classes, the teacher should pay attention to the grouping so that socially competent students support less competent peers (Webb et al., 1998). During the process, the teacher facilitates learning by encouraging independent work as much as possible but also offers support when required. It should also be noted that students must be given time to build their collaboration independently (Barron, 2003).

Further, variations in interactional processes between students can lead to productive collaboration (Barron, 2003). The collaboration requires an adequate division of labor (Barron, 2003) that is seen as more than just accomplishing a task because it involves agreed-upon but flexible roles and active interactions between team members. Although it is beneficial to participate equally, participants may also have various roles and relationships during the project (Mercier et al., 2014). The idea exchange may both facilitate and hinder ideation and tinkering, which is dependent on the quality of a teams' collaborative discourse interaction. Some students can take a leadership role or have more initiative; however, the level of initiation and intentionality (Gutwill et al., 2015) can change across the course of students' interaction (Mercier et al., 2014). Most commonly, the initiation and leadership are related to handing over certain tasks, checking on the following of the given instructions, coordinating the team members' attention, and directing the tools and materials used.

Appropriate social settings (i.e., a supportive atmosphere and close relationships, positive social norms, participant engagement, and social recognition of team achievements) facilitate participation for sharing ideas, organizing the process, and supporting the emergence of a commitment toward a shared epistemic object. Furthermore, teachers' interaction with students as part of organizing and facilitating teamwork is an important aspect of collaborative learning in school settings as well as in maker spaces (Gutwill et al., 2015). These include sparking initial interest, providing stimulus, giving demonstrations and modeling, making new tools and material available, and scaffolding participants through frustrating moments, as well as providing hints and help to teams to overcome challenges related to the division of labor and the distribution of the workload evenly (Gutwill et al., 2015). During the maker project, the teacher should actively pay attention to how the ideas are developed together and how the agreed-upon division of labor among the team members is realized.

From Self-Regulation to Co-regulation and the Socially Shared Regulation of Inventive Activity

The self-regulation, co-regulation, and socially shared regulation of learning are distinguished from one another (Hadwin et al., 2017; Panadero & Järvelä, 2015); a successful invention process is critically dependent on all these forms of regulation. Research on self-regulated learning assists in understanding and examining the role of intellectual, social, and emotional engagement in learning processes (Järvenoja & Järvelä, 2009). Järvelä and colleagues see self-regulated learning as a social process embedded in and mediated by a learning environment; it not only shapes personal activity but also that of other team members. Self-regulated learning refers to a student's capacity to manage their own activity, thinking, and motivation so as to achieve learning goals and objects. It also involves adapting one's own activity according to the team's shared objects, available tools, and epistemic and material resources, as well as the conditions of the learning environment (Järvelä & Hadwin, 2013; Järvenoja et al., 2015). Learning activities that rely on students' self-organized teamwork, collaborative interaction, and pursuit of novelty and innovation challenge students to interrelate their own activities with those of other team members and at the same time cultivate their self-regulative and collaborative competencies.

Co-regulation, in contrast, requires that the members of the team participate in the ongoing monitoring of mutual activity, cognition, emotions, and motivation (Järvelä & Hadwin, 2013). Panadero and Järvelä (2015) anchor co-regulation on Vygotsky's (1978) sociohistorical theory: Higher cognitive processes are assumed to develop through socially contextualized and tool-mediated interaction at the zone of proximal development. In the context of invention projects novel to all participants, co-regulation cannot merely be a matter of an asymmetric relation of more knowledgeable students supporting their peers but involves all team members and the task, tools, and learning environment providing reciprocal support to one another. Through teamwork, students are developing both their collaborative and metacognitive skills. Co-regulation is a metacognitive process of planning, monitoring, and directing team-based creative activity. The development of metacognitive skills requires that the students reflect on their own as well as the whole team's activities by asking about joint achievements, challenges, and required improvements of activity. In the context of team-based invention processes, metacognitive capabilities not only represent the personal awareness of one's own learning activity but expand to the awareness of socially distributed learning processes and the relevant knowledge and skills of fellow team members. Hadwin et al. (2017) argued that co-regulation plays a crucial role in fostering the development of both the self-regulation of learning and the socially shared regulation of learning (SSRL).

Learning in invention teams is mediated by the mutual pursuit of the shared ideas and visions of invention. Indeed, such an undertaking corresponds closely to SSRL (Panadero & Järvelä, 2015), which strongly underscores the object-driven aspects of the social regulation process. Shared regulation refers to a team's deliberate planning of its activity, the team members' co-configuration of the invention idea, the mutual shaping of the making processes, associated joint deliberation and reflection, and the reciprocal adaptation of activity. It is based on students' knowledge, beliefs, and experiences, which have to be mutually adjusted for the coordinated pursuit of the teams' shared epistemic object (Isohätälä et al., 2017,). SSRL requires that the team members jointly assume metacognitive control of the invention project in terms of negotiating and iteratively developing the invention idea and aligning teamwork activity cognitively, motivationally, and emotionally in pursuing the shared object (Hadwin et al., 2017). It means that the whole team should pursue the shared epistemic object as a collective after interactively working out the invention object and employ co-regulative efforts for successively forming as a team. SSRL is revealed in terms of active participation and mutual recognition and responsibility for achieving a common goal, that is, as a form of shared epistemic agency (Barron, 2003; Damşa et al., 2010). In such socially shared co-regulation of activities, the team members also observe and direct each other's activities (Panadero & Järvelä, 2015). Therefore, the team manages and directs the task in question through jointly agreed-upon methods and practices, but the members can also take on various roles during the process (Mercier et al., 2014).

In collaborative teamwork, reaching a shared understanding and elaborating a shared epistemic object are the most important aspects. Students' teamwork aims at making the invention. To that end, it is critical to support and strengthen the students' sense of belonging to a team and thereby increase each student's commitment to the joint invention project. A key part of the sense of belonging is a commitment to the shared invention process and agreed-upon ways of working. The cohesion of the team is enhanced by treating each participant equally, providing encouragement, and creating an adequate but flexible division of labor between the team members. Social interaction and open discussion in the team assist students in understanding each other's perspectives, making compromises, compensating for each other's weaknesses, and gradually building mutual practices. Understanding the skills and strengths of other team members is valuable when a certain kind of knowledge or skill is needed for solving a novel problem. The teacher can foster the development of teams' metacognitive skills by asking students repeatedly to reflect on their ongoing activity and advancement toward the artifact-in-making during the invention project.

The shared regulation of the invention process is a transactive process in which the initial epistemic object is invented, iteratively refined, modeled, prototyped, and manufactured. Accordingly, the invention project is not only a socially mediated process in nature but also a materially mediated one (Kangas et al., 2013; Mehto et al., 2020). To construct an adequately functioning artifact, the students have to employ diverse traditional and digital fabrication tools and multifaceted materials. Sociomaterial interaction with the various models and prototypes help the teams to explain, verbalize, communicate, and materialize initially vague ideas (Mehto et al., 2020). Further, the use of certain tools and materials is likely to impact the division of labor; the possession of a particular tool could, for instance, give authority in the use of the materials shaped by that tool (Buchholz et al., 2014; Rowell, 2002). Alternatively, the material mediation involved in making tangible artifacts enables all team members to observe the development and fabrication of the artifacts in making in real time; the material embodiment makes the diverging intuitions and expectations visible to all participants.

The focused social-creative pursuit of invention requires students to work toward a joint object; to listen to, understand, and help each other; and to engage in shared efforts of testing and constructing the artifacts being developed (see, e.g., Barron, 2003). The term process organizing (Riikonen et al., 2020) is used here to refer to the social-epistemic regulation of collaborative design and making processes. Such discourse interactions have been empirically identifiable across many investigations; they share characteristics of both the co-regulation and SSRL. The team members' belief in their capacity to solve the invention challenges requires unity, which should be supported in a range of ways. The teacher can see the togetherness of the team members in the way the students negotiate and build on the insights from each other's ideas, how they plan the task at hand, how they talk about the team's strengths and weaknesses, and how the members express their feelings about the task. Successful teamwork is clearly organized around joint problem-solving attempts, in which students have a shared idea of the designed object, and the team wishes to take the joint ideation forward. For the teacher, this commitment is clearly visible when the participants are talking about "us" as a team and referring to each other's ideas by expanding and developing them together. In the following, through two case examples, we will examine the level of socially shared regulation in invention teams.

Invention Project Settings and Method of Data Analysis

The two invention projects were organized at a primary and a lower-secondary school, respectively. In the project implemented in primary school, we explored collaboration and co-regulation in two inclusive teams including SEN students. In the lower-secondary school project, in turn, we traced the social regulation in the invention projects of five student teams. In both projects, student teams received an open-ended invention challenge jointly designed by the teachers and researchers. At the primary school, the student teams were challenged to "design an intellectually challenging, aesthetically appealing, and personally meaningful complex artifact making daily activities easier. It could be a new or improved invention, and it should integrate material and digital elements". At the lower-secondary school, the student teams were requested to "invent a smart product or a smart garment by relying on traditional and digital fabrication technologies".

The projects involved 8 to 12 weekly design and making sessions (two to three hours per session) over three months. The research data consists of video recordings of the seven teams. The fifth-grade teams worked on the Gel Comb and Key rack projects, and in the seventh-grade teams dealt with the Bike, Mobile Gaming Grip (MGG), Moon, UrPo, and Plant projects. We analyzed the video recordings using the Making-Process Rug method. Altogether, approximately 83 hours of video data were analyzed and coded in three-minute segments. The method of data analysis was based on two stages of (1) systematic coding of the video data and (2) converting these data into a visual form that enabled us to perceive the collaborative invention process and its flow. With that end in mind, the analysis produced color-coded, layered diagrams referred to as Making-Process Rugs because they resemble woven rugs (see Figure 4.1, which we have made available via the link in the footnote[1]).

From the visually coded video data together with ethnographic notes, we illustrated the commitment of the team members. The coded data provide a variety of indicators for assessing student teams' shared responsibility and motivation. These included (a) the extent to which the team members were involved in the activities and (b) how they focused on the specific activities or stages, (c) how much they were interested in the task, (d) how the members of the team interacted with each other, and (e) how the division of the work between members took place, that is, how the team members organized their collaborative process. Process organizing (see green color in Figure 4.1[1]) represents verbal interaction through which team members negotiated mutual responsibilities, talked about what should be done next, and analyzed the specific tools and programs needed in the next stage.

Findings

When analyzing teams' collaborative designing and making processes, some possible drivers of successful invention were identified. Extensive video data revealed each member's participation, engagement, and the quality of interaction between the members of the team. As the invention projects lasted 8 to 12 weeks, it is evident that the teams' engagement and intensity varied at different stages of the project. However, we were surprised that the student teams at both school levels were able to maintain their enthusiasm and motivation throughout their longitudinal invention processes.

Shared Responsibility at the Primary Level

At the primary level, we followed two inclusive student teams that we chose because of the participant structure, size of the team, and the team composition in terms of having both mainstream students and SEN students. Table 4.1 shows the team members and their inventions at the primary level.

In the larger Gel Comb team, students were divided into smaller sub-teams to work on their areas of responsibility. Some members were more active in advancing the invention, and they also directed the team's activities more than others. The Making-Process Rugs of the Gel Comb team revealed that the team had to repeatedly return to the process organizing, and the team also had more off-task work (see black color in Figure 4.1[1]), which can be interpreted as an inconsistency in the

Table 4.1 Primary school student teams and their inventions

Name	*Team*	*Basic idea*
Gel Comb	Five boys (three SEN students)	The Gel Comb is an invention where hair gel is applied directly to the user's hair so that the user's hands will not get dirty.
Key Rack	Three girls (one SEN student)	The Key Rack was intended to keep keys in a designated place with color-coded hooks for each family member's key(s).

team's activities and a challenge in terms of focusing on the targeted invention. The Gel Comb team reorganized its activities throughout the process and on several occasions during one session. The smaller-sized Key Rack team, in contrast, functioned in a very organized way right from the beginning, and the participation was more equally distributed, and the team was committed to promoting their invention process. The following three themes related to the regulation and organization of the teams' activities emerged from the material of the primary class: (1) shared responsibility, joint decision-making, and co-regulation; (2) reconciling tensions and dilemmas; and (3) social support, encouragement, and participation.

Shared Responsibility, Joint Decision-Making, and Co-regulation

In the Gel Comb team, one student had greater responsibility for the team's processes and the completion of the invention. The student took responsibility for the team's activities, and his leadership was manifested in terms of sharing instructions with others and the completion of tasks. Other members of the team relied on his opinions and his organization of work assignments. The student was also responsible for involving other team members and personally completing tasks that might otherwise have been left undone. Although in the Gel Comb team the members gave the main responsibility to one student, they mainly shared their decision-making in the team.

In the Key Rack team, there was no single leader or responsible person; rather, the process was more evenly co-regulated among the students. There was constant consultation between the two mainstream students about who was allowed to make decisions, such as who was responsible for writing the learning diary or what the invention should eventually become. They both had a strong desire to take responsibility and make decisions. However, the authoritarian attempts of an individual student to regulate team activities were thwarted, and the students sought to make team decisions jointly. In particular, the third student played an essential role as a mediator. Joint decision-making appeared to be important in both teams.

The activities of the invention teams were jointly co-regulated within the teams in many ways. The co-regulation aimed to ensure that the activities of the teams were continuous and desirable. In the Gel Comb team, the participation in the invention process was organized by regulating the behavior of the team members, particularly limiting off-task activity. The manifested leader often asked the other team members to focus on the essentials, calm down, and listen to each other. He emphasized the importance of focusing on the work for completing the invention, and he patiently structured the activity of the other members by guiding and encouraging them. Despite strong leadership, the activities of the Gel Comb team were more fragmented than those of the Key Rack team. The larger the team size and the larger the number of SEN students in the team may have contributed to the challenges of focusing on the main activities.

Participation in team activities and interactions can be considered to be one of the critical dimensions of collaboration. The team members regulated each other's behavior by obligating them to participate in joint activities. The obligation was manifested explicitly and verbally to focus on the task at hand or participate more actively. Invitations to concentrate on the task were especially addressed to the

SEN students in both teams. In both teams, the SEN students sometimes lost focus until they were encouraged to return to the invention. In both teams, efforts were made to find suitable tasks for each team member even though the situation might not have required that activity.

Leadership, responsibility, and social support may appear to be more prominent forms of team activity, but participation in social interaction is also essential. Learners who for one reason or another are unwilling or unable to take on a visible role in their team's activities may still bring their own way of taking part in creating the social order. This was the case especially with SEN students. For example, in the Gel Comb team, one SEN student's role as being socially funny may seem disruptive; nevertheless, the student participated in social interaction, brought out his ideas, and created a friendly, lighter atmosphere for the team by having fun with others. Although the responsibility for team activities was not evenly distributed among the team members, and commitment to team activities varied during the project, neither team completely excluded any members from team activities.

Reconciling Tensions and Dilemmas

There are many challenges in the invention process and the team seeks to address these together through a range of ways to strengthen collaboration. Conflicts that arise in collaborative situations can allow students to take on a new kind of responsibility for team activities, participate actively, and thus express their role by calming the situation and contributing to the smooth continuation of team activities. In the Key Rack team, there were several conflict situations. Disagreements arose between two mainstream students; their close friendship outside the project may have influenced the situation. Interestingly, the SEN student took the initiative to keep the group dynamics harmonious by addressing disagreements between the other team members. For example, she resolved a potential conflict even before it broke out by intervening in a discussion that had turned into a debate between two members; she encouraged each student to have their say and thus allowed all members to express their own opinions in order to resolve the situation. Her effort of giving turns and asking questions was proactive in nature, which may be interpreted as an expression of the student's agency in relation to SSRL.

The difficulties of the Gel Comb team were different. They appeared as a continuous reorganization of the process and a lack of focus concerning targeted action. However, there were no actual emotional episodes that could be classified as conflicts in the Gel Comb team. The tensions of the Key Rack team, in turn, arose when the team members did not meet their implicit quality requirement or when joint decision-making turned out to be difficult. Disagreements within the team swelled to interfere with targeted team activities when a lot of time had to be spent resolving them and when they became emotional and offensive. However, the team resolved the conflicts together, and activities continued. Despite the Key Rack team's disputes, the videos show that keeping the team together was vital to all members. Disagreements appeared to strengthen the Key Rack team and focus the team's activities on the invention after conflicts. With persistent cooperation, both teams completed their inventions.

Social Support, Encouragement, and Participation

Overcoming tensions and dilemmas together can strengthen the team and support its activities later. In both teams, students also provided each other with social support, encouragement, and guidance during the invention process. By supporting and encouraging others, it is possible to increase the sense of contribution, thereby strengthening the role of the actors in the team (Sormunen et al., 2020). The Gel Comb team's video material revealed that the students recognized each other for a job well done. For example, the students praised the contribution of the slightly passive SEN student. Positively encouraging an individual about their own work can strengthen their sense of contribution, which in turn can enhance agency and a sense of inclusion (see, e.g., Damşa et al., 2010). Also, at many points in the Key Rack project, the members encouraged each other and considered the effects of encouragement and positive support on the team's good atmosphere.

Experiences of the Social Regulation of the Invention Project at the Secondary School

In the secondary school project, the size of the teams varied from three to seven members, which clearly affected the teamwork (see Table 4.2). All students were mainstream students. The results indicated that four of the five teams were able to take on multifaceted challenges and come up with novel inventions.

The analysis of the video data revealed that the collaborative processes within the larger teams (six to seven members) were more fragmented than those in the smaller teams (Riikonen et al., 2020). Moreover, off-task work was more common in the larger teams than in the more compact ones. The following three aspects related to co-regulation and process organization emerged from the data: (1) joint commitment and engagement, (2) importance of model making and experimentation, and (3) topics of process organizing.

Table 4.2 Secondary school student teams and their inventions

Name	*Team*	*Basic idea*
Bike	3 boys	A three-wheel bike containing smart technologies, such as an environment-responsive, rechargeable LED lighting system
MGG	4 boys	MGG, a pair of handles that improves the ergonomics of a mobile phone while playing games
Moon	6 girls	A smart outfit for sports, including an environment-responsive lighting system to improve safety
UrPo	6 boys	A smart insole for sport shoes, including an automatic warming system for winter sports
Plant	7 girls	An automatic plant care system incorporating decorative elements

Joint Commitment and Engagement

In most of the teams, the design challenge clearly appeared to be transformed into a joint effort for the team as the project progressed, that is, a joint commitment and shared engagement to develop their own inventions. Only one team (the Plant team) really found it difficult to find commonly shared ideas and to organize their process together. Moreover, other large teams appeared to have some problems engaging all team members in working consistently to advance their invention. However, when the design process proceeded, all members were able to participate equally. The interaction between the members of the team was generally positive, and the resulting conflicts related to the divisions of work were solved by consensus, thus fostering collaboration within the team. This is important as negative socio-emotional experiences may challenge the teamwork and undermine the team's chances for success (Barron, 2003).

The smaller teams were more committed and enacted the socially shared co-regulation more readily. During their design and making processes, the teams produced multidimensional and relevant ideas for inventions to drive their design forward into more specific ideas and new products. Although the members of the team could have different ideas or views related to the ideas of invention at various stages of the process, they nevertheless endeavored to produce the best possible joint solution and to consider each other's views. Beyond team size, group dynamics and the nature of the inventions may have also affected the observed differences.

Importance of Model Making and Experimentation

The data analysis revealed the importance of model making in the successful completion of the making process (Riikonen et al., 2020). In the processes of the Bike, MGG, Moon, and UrPo teams, model making was the most noticeable activity that was intertwined with ideation, with discussion about manufacturing and evaluation occurring either in parallel or following model making. These teams dealt with the complexity of invention challenges by spending a great deal of their time in model making and digital experimentation. The importance of tangible, hands-on work for the successful teams is also emphasized in the results of previous studies (Kangas et al., 2013). Therefore, it can be argued that without the creation of prototypes, there would have been a lack of fruitful opportunities for shared regulation. The model making gave the proposed solution a tangible form, enabling the evaluation and acceptance or rejection of the prospective solution, and helped the members to focus on joint decision-making. The prototypes integrated the ideas and solutions and materialized all aspects of the team's invention. Sociomaterial engagement (Mehto et al., 2020), both in materially mediated making and in focused social interaction, was critical in inventing tangible artifacts. The Plant team did not engage in any model making over the course of the project, and the team spent most of its working time on off-task actions. For example, they experimented with materials and digital tools, but these experiments did not lead to model making, and the potential to advance their invention never materialized: they were not able to develop a shared understanding of the object.

Topics of Process Organizing

Common to most of the successful teams was concentration on shared working and a commitment to it. The process organizing involved the social-epistemic regulation of collaboration to engage in shared efforts of testing and constructing the artifacts being developed. The topic of process organizing focused on:

1) Organizing making activities covering the discursive aspects of doing or performing something, including discussions concerning next steps, such as 3D modeling, sewing fabric, or searching for more information about coding LED lights
2) Constraints and resources, including discussions on how to find certain materials, scheduling future activities, or acquiring social resources such as help from a teacher, and finally
3) Teamwork, covering how various tasks would be divided among team members

The Bike and MGG teams focused on organizing making activities and tight teamwork among all team members. In the MGG team, one student had a leading role in the organizing process, but he provided the other team members opportunities to participate. Further, the lack of teacher involvement was striking in both teams, and the teachers were only needed to provide assistance in deciding how to proceed or material resources and guidance regarding 3D printing (for example). In the Moon team, the design and making processes were also organized in a very collaborative manner through negotiations within the whole team, and they composed sub-teams to conduct certain tasks. The UrPo team's process organizing was led by the two team leaders and supervised by the teacher. It was rare in the Plant team's process for the entire team or even most of the members to take part in organizing the process.

In general, the teams' engagement evolved as the teams' solutions advanced: they enjoyed problems-solving and making, and the teams' activities were self-regulated. Their own meaningful invention challenge combined with the freedom of making choices can be seen as major elements contributing to the creation of the shared objectives of the internally motivated teams. For example, the teams did not discuss the teacher's expectations about their invention projects; instead, the discussion and activities focused on the realization of a shared object and the setting of the teams' own goals on the basis of their own starting points. The teams' collaborative process of organizing can be characterized by joint project management, continuous shared responsibility, and mutual control of the various aspects of the multifaceted project.

The successful teams managed to sort out most of the teamwork challenges themselves, and they addressed related issues in most sessions. Thus, the commitment and co-regulation of shared working appeared in terms of enjoyment, capability, orientation toward destination, and commitment to problem-solving. Developing their inventions together and the shared motivation among the team members seemed to constitute a self-inducing positive cycle in which the team members became increasingly motivated to achieve the objectives they had set, which in turn encouraged the team members to set new goals and to work hard to achieve them. However, as stated earlier, such corresponding shared motivation was not observed in only one team: the team did not develop common problem-solving goals that would have created commitment within the team members to develop their own invention. On the contrary, over time, these students made it clear that they did not have inner motivation and were not able to organize their process.

Discussion

The aim of the invention projects was to provide a variety of students with the experience of participation, that is, to persuade them to make something relevant together, thereby stimulating their internal motivation, referring to the desire to promote commonly agreed-upon objectives and to commit to the completion of the project. In teams, the close commitment and positive attitude and flow reinforced the view of how important it is to develop teams' inner motivation and commitment to their work. It can be said that in both school cases, most of the teams had positive learning experiences in terms of having ambition, dedication, and flow. The achievement of positive learning experiences as part of the curriculum content can be regarded as significant, and these experiences may have far-reaching implications as students move to adulthood and to the world of work.

Equal participation and the sharing of tasks evenly promoted the co-coordination of the team's activities, which is a prerequisite for successful collaboration. The unclear role of the students in the group interferes with the teamwork. Working in small teams in which all members interact actively to achieve a shared goal and object is usually inspiring and creates a positive cycle. Creativity in designing requires the bravery of the members to present their own ideas and experience. The quick drawing of ideas and testing of details are situations in which joint work becomes visible. When working is at the center, students convey and make visible their design ideas through discussion, drawings, and various material 3D models and prototypes. This provides an opportunity for further processing ideas and discussing them and producing more advanced ideas. However, getting students into this state of mind may be challenging as they may have varying skills and knowledge, and the teams may thus be highly heterogeneous.

In the primary class project, the activities of the teams were co-regulated in many ways. Shared responsibility for the team's activities was taken both at the individual level and collectively. Making decisions jointly was sought, or team members gave one team member the responsibility for leading the team's activities and the division of labor. The teams regulated activities to influence the behavior of other team members, involved all team members in joint tasks, and resolved any difficulties and disagreements that arose during the project. The team members gave each other additional social support and encouragement to ensure harmonious and smooth group activities. Students sought to compromise, work together, and keep the team together during the project. Working together was perceived as meaningful.

Directing the teams' motivation and interest toward a common goal may become a challenge for joint activities. This is influenced by the instructions, open-ended but jointly negotiated and comprehensive assignment, and previous experiences of school practices. Further, the team must put joint effort into working out the shared epistemic object of their activity; that is already an achievement rather than something pre-given. Collaborative learning also takes shape differently depending on whether the members of the team are allowed to choose their own team and working space or whether they participate in collaborative activities on their own initiative, on the initiative of a teacher, or under compulsion. In addition, during the long-term invention project, the motivation, commitment, and dynamics of the team members may vary.

The teacher can assist in the accomplishment of effective collaboration by monitoring the interaction between team members and by scheduling the various stages of the invention project—and also by practicing it with students, getting them to use nonlinear working, and managing anxiety. In inclusive classes with SEN students, collaboration and co-regulation can be supported by creating different routines for working, including starting sessions with the team's joint review of ongoing phases (where we are now), what should be achieved during this session, and at the same time, agreeing on which team members are responsible for which phase or sub-task. At the end of the working session, it is also important to reflect briefly on how the objectives of the working session were achieved, whether everyone has had enough opportunity to contribute, and how collaboration between the members of the team has proceeded. Agreement on the division of labor can be reviewed separately in each session.

Note

1 https://growingmind.fi/inventionpedagogy_makingprocessrugs/

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