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Expansive Learning in Teacher Education's Hybrid Spaces: The Challenges and Possibilities in and Beyond Learning Studios

Jeroen Imants, Paulien C. Meijer and Erik Blankesteijn*

Radboud University Nijmegen, Radboud Teachers Academy, Nijmegen, Netherlands

This article uses the concept of expansive learning from activity theory as a lens to understand learning in and beyond hybrid or third spaces in teacher education. In so-called "Learning Studios," student teachers, experienced teachers and teacher educators learned through exploratory activities, leading to new insights, "familiarized knowledge" and expanded practices. However, while learning in Learning Studios was supposed to affect schools and universities (as activity systems), labeled as "snowballing," this only occurred sporadically. Using expansive learning theory and its prominent role of contradictions, we developed a better understanding of—and explanation for—the lack of snowballing. We developed suggestions for snowballing in schools and universities based on the successful characteristics of learning in Learning Studios.

Keywords: expansive learning, teacher education, hybrid spaces, teacher learning, professional learning communities

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****Correspondence:***
Paulien C. Meijer
p.meijer@ru.nl

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INTRODUCTION

Over the last few decades, institutes for teacher education and schools have increasingly collaborated in networks that focus on the internships of student teachers, the introduction of new teachers in schools and professional development of experienced teachers. One of the reasons for the introduction of these networks is the growing problem of teacher shortages. Partly, these shortages are caused by the fact that a relatively high number of beginning teachers leave the profession within the first 5 years of teaching (e.g., Ingersoll, 2001; Borman and Dowling, 2017). Several experiments are initiated with the aim of solving this retention problem. School-university networks are assumed to contribute to that aim.

Most of the time, programs for interns and beginning teachers include elements of mentoring or coaching by experienced teachers and of collaborative reflection with other interns or beginning teachers (Ingersoll and Strong, 2011). These programs depart from the idea that there are still many skills to learn for newcomers. More recent programs have attempted to go beyond this so-called "deficit model" of support for beginning teachers (März and Kelchtermans, 2020). The programs have come to see beginning teachers not only as learners, but also as bearers of new ideas, and as connoisseurs of the younger generations. Viewing them as such creates space for interns and newcomers in quite a new way, as well as space for experienced (mentor) teachers' learning (e.g., Hong and Matsko, 2019). Despite these developments, how student teachers, early-career teachers and experienced teachers learn while interacting in schools as workplaces is still underexamined

and not well-understood. As a result, student teachers see schools as separate from their teacher education program (e.g., McGarr et al., 2017).

On top of the problem of teacher shortages, several developments have changed the situation for experienced teachers as well. In many countries, schools have grown bigger, classes have increasing numbers of pupils with a rising number of cultural and linguistic backgrounds, and societies demand an increasing number of tasks and responsibilities from teachers, sometimes even in relation to worldwide challenges such as a sustainable planet and climate change (cf. Meijer, 2015; United Nations, 2015). This places higher demands on teachers, and the need for their continuing education is growing accordingly. Many schools are struggling with this, and one of the questions is how networks of universities and schools can or should play a part in addressing these demands regarding continuing professional and school development.

The last decade revealed a shift in attention from teacher learning aimed at teachers' further growth toward teacher learning that, in addition, leads to changes in the teachers' professional context, including school improvement (Imants and van der Wal, 2020). However, conditions that apply to teachers' individual learning, described by, for example, Van Veen et al. (2012), do not automatically account for this broader purpose. In fact, new conditions might be needed to be able to address this, but not enough is known about the processes that are involved in initiatives that successfully focus on both types of development (individual teacher growth and school improvement). Studies have shown that initiatives aimed at both individual professional growth and school development often lead to individual growth only (e.g., Imants and Oolbekkink, 2009). "Snowballing" toward development beyond the individual participants, let alone toward school improvement, appears to be notoriously difficult, as initiatives for teacher-researchers in schools show (e.g., Meijer et al., 2013). In such initiatives, teachers are expected to become catalysts in their school to develop an inquiry stance on the part of their colleagues, or to develop a research culture in their schools. Several studies have shown that these projects were often very successful in terms of teachers' personal professional growth, but that any development beyond that was absent or lagged behind (for an overview see Meijer et al., 2013). This might be explained by the fact that in initiatives that aim beyond teachers' individual learning, the conceptualization of learning is not automatically clear. The processes that are aimed for are multilayered in terms of both products and processes.

With this in mind, a network of universities and schools developed hybrid learning environments, or "Learning Studios," in which student teachers from four universities as well as beginning and experienced teachers from related schools participate to learn and develop together. An important difference from the traditional relationship between student teachers and mentor teachers is that the roles of teacher and learner continuously alternate between all the participants. A teacher educator from a university participates as a coach and as a learner as well. Learning Studios are regarded as a specific form of professional learning community. Every week for 1 school year they meet for one morning, during which they depart from their own questions and concerns in relation to pupil learning. Learning Studios are not only aimed at the professional development of the individual participants, but also at exploring ways to disseminate their learning, thereby affecting the school and university environments and, as a spin-off, contributing to reconsideration of the teacher education curriculum (Koopman et al., 2019).

The hybrid environment of Learning Studios demands a reconsideration of how to conceptualize and understand the processes and outcomes of student teachers' and schoolteachers' learning. This hybrid environment includes many potential contradictions, meant as catalysts for learning. However, without careful attention, learning will be impeded and certainly the type of learning beyond the individual will not take place, as described in earlier studies. Potential contradictions include the types of knowledge that play a role (knowledge at schools and knowledge at universities), conventions (at school and university) and innovations, and individual development vs. the development of schools and universities. In this article, we depart from Engeström's concept of expansive learning (part of his activity theory) to explore the mechanisms that underlie the types of learning in and surrounding the Learning Studio, and the outcomes of this learning. Activity theory might make a suitable framework for the analysis of learning by all participants in this context, for the following reasons:

- Expansion of the unit of analysis of learning beyond the level of the individual; focus on collectives as learners;
- Commitment to pedagogical and interventionist actions to facilitate and change learning;
- Expansion of the unit of analysis from a single activity system to two or more interconnected activity systems; learning in interorganizational networks; growing importance of partnerships between organizations;
- Transformation of conflicts and tensions into a third space as a rich environment for learning.

The aim of this study is to analyze the how and what of learning in Learning Studios, and to explore dissemination and spin-off for schools and universities. In the theoretical framework, insights from the work on professional learning communities (PLCs) and Activity Theory are introduced. PLC insights are used to analyze the dynamics of the internal functioning of Learning Studios; activity theory is used to analyze the how and what of learning within the broader context of the network of universities and schools, in which Learning Studios are positioned as third spaces.

THEORETICAL FRAMEWORK

Characteristics of Professional Learning Communities

Van Meeuwen et al. (2019) reviewed studies on professional learning communities in secondary education from 1990 until 2018 and came to distinguish 11 characteristics and three steering instruments for professional learning communities in secondary schools. Together, these characteristics and instruments make a comprehensive and dynamic conceptual framework for

researching and enacting professional learning communities. The 11 characteristics cluster in three groups: (1) *individual and collective learning*, including collaboration, reflection, giving and receiving feedback, and experimenting; (2) *group dynamic characteristics*, including mutual trust and respect, collegial support and social cohesion; and (3) *professional orientation*, including shared vision, shared responsibility, shared focus on student learning and shared focus on continuous teacher learning. These characteristics are summarized in **Table 1**.

Professional learning communities always function within a broader context of schools and/or universities. Steering instruments are required to create sustainable opportunities for professional learning communities to be productive. Van Meeuwen et al. (2019) identified the following three steering instruments: (1) leadership, (2) autonomy of the community, and (3) facilitation of the community.

Together, the characteristics of professional learning communities and steering instruments as identified by Van Meeuwen et al. (2019) can be assumed to be more or less prominently present in the functioning of Learning Studios (the how question).

Learning Studios and Activity Theory

Learning Studios were set up within a network of several universities and secondary schools (cf. Koopman et al., 2019). It was assumed that this network and the organizational actors within this network would have a serious impact on the functioning and the outcomes of these Learning Studios. Moreover, outcomes of Learning Studios were assumed to contribute to new forms of teaching and learning in universities and schools. Where insights from studies on professional learning communities focus on the *internal* processes in Learning Studios, insights from activity theory are used to study the functioning and the outcomes of these Learning Studios within this complex network environment.

In this section, we build strongly on four articles that focused on activity theory and expansive learning (Engeström, 2001; Engeström and Kerosuo, 2007; Tsui and Law, 2007; Engeström and Sannino, 2010). According to these authors, activity theory expands the unit of analysis of learning beyond the level of the individual; the focus is on *collectives* as learners. Also, activity theory expands the unit of analysis from a single activity system to two or more interconnected activity systems. Activity theory is about learning in interorganizational networks. In this study, the Learning Studio is seen and analyzed as a separate but interconnected activity system within university and secondary school activity systems.

Following activity theory, the interactions between universities and secondary schools as networked activity systems result in the transformation of conflicts and tensions within and between universities and schools into a third space as a rich zone of learning. We regard Learning Studios as third spaces. Activity theory can be helpful in exploring and explaining the expansion of learning within these Learning Studios to learning in the activity systems of universities and secondary schools.

In activity theory, "activity" is the mediating entity between the individual and social dimensions of human development. Individual and group actions are embedded in activity systems that are collective and social in nature. In activity systems, participants engage in common social processes through which meanings are (re-)developed and through which the culture of the activity system is (re-)produced.

In activity theory, the concept of *object* is of crucial importance. There is no activity without object, and object embodies the meaning, the motive and the purpose of a collective activity system. Activities are realized by goal-directed actions. These goal-directed actions can be regarded as specifications of motives that are expressions of the objects of the activity system. The motive of an action is its object. Objects cannot be reduced to short-term acts of specific participants. Objects give direction and meaning to specific outcomes of activities by participants/subjects. One way in which the activity system of a university can enact its objects is by enriching the teacher education program and apprenticeships by transferring positive results and insights from the Learning Studio to the university context. The activity system of the school can enact its objects by enriching the school curriculum and teaching practices through the diffusion of positive results from the Learning Studio through the school context.

TABLE 1 | Professional learning community characteristics (based on Van Meeuwen et al., 2019).

Individual and collective learning	Group dynamic characteristics	Professional orientation
Collaboration: Researching, developing and implementing the shared educational practice together *Reflection:* Individually and jointly questioning daily practice to improve this practice and to evaluate the process of the learning community *Feedback:* Sharing information on teaching practice in relation to the ambitions and goals, to improve teaching practice *Experimenting:* Individually, collectively researching new or altered attitudes, approaches and materials in repeated cycles	*Mutual trust and respect:* Supportive, affective and safe climate where problems and convictions can be voiced *Collegial support:* Teachers devote care and attention to each other; stimulate teachers to share their teaching practice beyond a superficial level *Social cohesion:* Feeling of wanting to belong to the group	*Shared vision:* Shared ambitions and attitudes: a common frame of reference regarding teaching and student learning *Shared responsibility:* Teachers take collective responsibility for learning from and with each other, as well as for student learning, and act accordingly *Shared focus student learning:* Permanent focus on improving student learning *Shared focus teacher learning:* Teachers' ongoing professional development during their career to improve their own learning and the learning of students

In this article, the two interacting activity systems are the secondary schools that participate in the Learning Studio and the teacher education departments of the participating universities. The third activity system is the Learning Studio, positioned as a third zone in between the university and the school. In this third space, more encompassing objects or motives for the activity are constructed, and these are meant to result in transformed activity systems. These activity systems and how they interact are depicted in **Appendix 2** (Supplementary Material). In this appendix the complexity of the interrelationships between the three activity systems is elaborated and visualized, according to activity theory literature.

To reduce the complexity in the figure of **Appendix 2** in Supplementary Material the content of the figure is summarized in **Table 2**. **Table 2** reflects the differences in how the various elements play out for the three activity systems of schools, universities and Learning Studios.

Learning Studio as a Third Space

"Third space" refers to a place where elements of two activity systems are present and interact. Characteristic of the Learning Studio is that within this third space all the participants continuously change between the roles of learner and teacher. School teachers (eventually mentor teachers), student teachers and the coach all take the role of teacher and learner alternately within the Learning Studio. In a "third space," learning takes place when ideas from different cultures meet and form new meanings. The Learning Studio is a third space in which the activity systems of universities and secondary schools are connected and interact dynamically, because in the division of labor the roles of teacher and learner are not rigidly prescribed for diverse subjects from schools and universities. The specific objects of Learning Studios are:

a. Developing student-centered and innovative approaches to teaching and learning in secondary schools; the learning of the secondary school student is central;
b. Professional development of student teachers and secondary school teachers in a shared and rich learning environment.

Aspired outcomes of student teachers in the Learning Studio are:

a. Becoming qualified and well-educated teachers in secondary education;
b. Connecting theory and practice of teaching by participating in the learning studio.

Aspired outcomes of school teachers/mentor teachers in the Learning Studio are:

a. Connecting own practices to theory and research and as a result deepening insights into own practices;
b. Improving own teaching practices by designing and exploring new study tasks and courses/classes for students.

As can be seen, university and school objects are not the first priority in these two Learning Studios. The focus in objects is on the learning and qualification of participants and the development of secondary student-centered teaching practices.

TABLE 2 | Elements of activity systems.

	Activity system		
	Schools	**University/teacher education department**	**Learning Studio (third space)**
Objects	a. Educating secondary students effectively and efficiently, and preparing these students for being successful in final national examinations; b. Contributing to optimal preparation of student teachers as interns in schools	a. Delivering well-qualified teachers for secondary education; b. Contributing to scientific and practical knowledge on teaching and teacher education; c. Developing in-service teachers professionally	a. Developing student-centered and innovative approaches of teaching and learning in secondary schools; b. Shared professional development (qualification, improvement) of student teachers and secondary school teachers
Subjects	School teachers, mentor teachers, student teachers, school management	Student teachers, teacher educators/professors, management of department	Student teachers, school teachers (in some cases also mentor teacher of student teacher) and the coach (teacher educator/professor)
Division of labor	School teachers act as mentors for student teachers; student teachers teach classes as part of their apprenticeship; school management facilitates	Student teachers learn to teach; teacher educators and professors teach them; management of department facilitates	No fixed roles.
Mediating tools	Classes for secondary students, teaching materials that are available within the school, etc.	Classes for student teachers in the regular program, teaching materials, etc.	a. Sessions that consist of a variety of activities, exercises and assignments; b. Learning questions of participants
Rules	School curriculum, grading and examination regulations and requirements, and regulations regarding the apprenticeships of student teachers that are developed under supervision of, and in collaboration with, universities	Teacher education curriculum, examination requirements and regulations, and regulations with professional development schools regarding mentoring of student teachers as interns, including formal supervision of these student teachers	Norms and practices of equality in participation, openness, inquiry and trust are central; uncertainty is regarded as a source for learning
Community	Secondary school and, at a distance, the larger school board	Department itself and the complex entity of the university and the university faculties	All participants or subjects

Contradictions and Tensions

Activity theory views contradictions and tensions as driving forces for learning. The internally contradictory and historically changing character of the activity system plays a central role in this dynamic learning process (as objects of systems and of participants within the systems might contradict, and as the results of continuous discussions in society about education between changing coalitions of participants). The structural sources for potential contradictions and tensions in and around the Learning Studios are:

(1) The tension between conservation and change; expectations in society regarding education always shift between these two poles. Both universities and schools have to deal with this structural educational contradiction. Under ambiguous conditions the pressure to reposition education continues all the time. This tension between tradition and change, or routine and innovation, occurs within the teacher education departments as well as in the secondary schools. This structural tension reoccurs in the Learning Studios as a third space in a specific way, because of the focus on student-centered innovative practices for teaching and learning.

(2) The differences between the educational systems of university and secondary education; a tension that is central in this study regards the difference between codified and tacit knowledge. In the education of student teachers at universities the focus is on the translation of dynamic scientific knowledge into codified knowledge about teaching and learning, and on the transmission of this codified educational knowledge to student teachers. For secondary school teachers, tacit knowledge about secondary education and its students plays a strong role. Transfer of this personal and implicit knowledge is hard to realize within and outside the schools. Transfer implies some kind of articulation and specification, resulting in codification. In common language this tension is often discussed as the gap between theory and practice. We think this label of theory-practice gap misses the point of the second structural contradiction in the Learning Studio. We put the tension central between codified knowledge and tacit knowledge, related to university and school.

(3) The tension between the individual professional development of participants in the Learning Studio and the broader outcome of snowballing that is aspired to by universities and schools in the larger network. In the curricula for students in secondary schools and universities the qualification of these students and student teachers as individual learners is a prominent goal. In this respect, school and university cultures both have a long tradition in representing the image of outcomes of learning and education as assets that are coupled to individual qualifications. The aspired effects of snowballing are organizational gains. In traditional university and secondary school views on learning, organizational gains are not considered to be outcomes of learning. In these educational contexts, learning is not regarded as a collective activity that, according to activity theory, leads to transformation in activity systems.

The discourses in the activity system of the Learning Studio afford opportunities for transformation of these contradictions and tensions in a rich zone of expansive learning. More encompassing objects or motives for activities can be constructed, eventually resulting in transformations in the activity systems of universities and schools. Expansive learning in the Learning Studio, and in universities and schools, is triggered by existing practices being questioned, rather than by a given learning task. However, the expansion of learning processes and outcomes from the Learning Studio toward universities and schools is not self-evident. Connections and collaboration between universities and schools themselves may be beneficial but they do not guarantee that the object of joint activity is transformed in a productive way. Some opportunities for, and hindrances to, this snowballing form a central theme in this study in relation to the what and how of learning within the two Learning Studios.

Expansive Learning Resulting From the Learning Studio

Expansive learning that results from the Learning Studio relates to the objects of the Learning Studios, as well as to the objects of universities and schools in terms of the snowballing effect. In mainstream learning theory, outcomes of learning are often defined in terms of gains in knowledge and skills and of changed patterns of behavior of individual learners. In activity theory, outcomes are expanded objects and new work practices, including practices of thinking and discourse. The results of expansive learning form a triplet:

1. Expanded pattern of action
2. Corresponding theoretical concept
3. Specific manifestation of agency of participants/subjects.

In Learning Studios, expanded patterns of action concern the innovative classes and study tasks that are developed, tested and evaluated by school teachers and student teachers. Related to these practical exercises, participants discuss theoretical concepts and develop specific meaning for these concepts. These actions occur in Learning Studios as a newly formed community, in which specific manifestations of participants' agency represent their enactment of self-directed learning goals and practices. Expanded patterns of action between the Learning Studios and the universities and schools (snowballing) concern the transmission of the curriculum, teaching and learning in universities and schools that is based on successful practices developed in the Learning Studios. Moreover, reflections in universities and schools on these successful practices can affect codified and tacit knowledge that dominate discourses in universities and schools. This might be accompanied by specific forms of agency for teachers in universities and schools.

Connecting the Professional Learning Community Framework and Activity Theory

In this study, the activity theory framework is used to answer the how and what questions regarding learning in and around

TABLE 3 | Overview of instruments.

Instrument	Overview of topics/starting questions
Observations	• Content of learning (what) • Process of learning (how) • Interaction in the network (who learns from whom) • Giving and asking help • Reframing of questions, topics and findings • Mutual reinforcement
Group interview	• What have you learned? • How have you learned? • Function of the group • Role of the coach • Focus on secondary school student learning

TABLE 4 | Overview of codes used in this study.

Research questions	Codes
Research question 1: Processes	• Learning processes/activities • Patterns in activities during meetings/sessions • Collaboration • Internal network: who learned from whom • Role of coach • Other leading/supportive activities • Satisfaction with learning activities
Research question 2: Outcomes	• What learned • Learned from whom/what • Products delivered • Relationship with own goals.

Learning Studios in a comprehensive way, including the question regarding snowballing from Learning Studios to universities and schools. In addition to activity theory, the professional community framework is used to analyze the social dynamics within Learning Studios. This framework is specifically linked to the how question.

This article deals with the following questions:

1. What does learning look like in Learning Studios?
2. What are the learning results/realized outcomes for participants of Learning Studios?
3. How are the learning processes in, and results of, Learning Studios related?
4. What role do contradictions within the Learning Studio concept and practice play in processes and results?
5. What results from Learning Studios affect the activity systems of universities and schools (snowballing)?

METHOD

Participants

Two Learning Studios were analyzed for this study. Three school teachers, four student teachers and the coach participated in LS 2017–2018. Two school teachers were also mentor teachers for two student teachers. Three teachers, four students teachers and the same coach participated in LS 2018–2019. Again, two school teachers were also mentor teachers for two student teachers. All participants were teaching in history, culture and art history, or social studies. The coach was specialized in Mother Tongue Education and communication theory.

Data Collection

Data were collected each year by means of an observation of an LS session, two group interviews and a questionnaire.

The observation and the first group interview were combined in one session during the first half of the year, after 2 to 3 months of functioning of the LS. **Table 3** presents an overview of observations and interviews.

The questionnaire was administered during the second half of the year and completed by all individual participants. It contained 11 questions regarding motivation for participation, learning aims, themes that were central in the Learning Studio, how the respondent learned and learning gains for the respondent. Alternatives for answers were offered and more than one alternative could be selected. Moreover, every question asked respondents to clarify the selected alternatives and complete the alternatives with their own answers. The completed questionnaires were the starting point for the second group interview at the end of the year. Compared to the first group interview, this interview had a stronger focus on the learning results and products.

Data Analysis

All observations and group interviews were recorded by video or audio. Transcripts were made of all observations and interviews. Transcripts of the observations were completed with field notes about the group dynamic and other characteristics of the sessions of the Learning Studios.

In the initial data analysis, the transcripts were coded (see **Table 4**) with a focus on the "how" and "what" questions (research questions 1 and 2).

As a next step, relations between processes and outcomes were examined (research question 3). During this step, contradictions became evident (research question 4). During the final step, explicit attention was paid to signs of "snowballing": indications that outcomes or processes in the Learning Studios affected (one of) the activity systems "school" or "university" (research question 5).

Below, results from these steps are described and illustrated with meaningful episodes during the sessions and activities of the two Learning Studios, summarized from the transcribed data.

RESULTS

Learning Processes in the Learning Studios[1]

The results regarding the learning processes are presented according to the characteristics of professional learning communities (PLCs). *First*, we found that the learning processes in the Learning Studios were alternately intense and relaxed, and collective as well as individual. *Second*, the group dynamics

[1]The Day-to-Day Functioning of the Learning Studios Is Described in **Appendix 1**.

appeared to characterize the Learning Studios as PLCs. *Third*, the results indicate a new perspective on "sharing" in the PLC characteristic of professional orientation. This section ends with a short discussion on how the steering instruments for PLCs [i.e., (1) leadership, (2) autonomy of the community, and (3) facilitation of the community] played out in the Learning Studios.

Intense and Relaxed as Well as Collective and Individual Learning

All participants found that learning in the Learning Studios was alternately intense and more relaxed. Interestingly, individual learning took place in parallel to collective learning. Both were felt to be equally important, and highly interdependent. Two examples of intense and collective learning episodes are presented below: a work session on a mind map and a work session on the development of an observation instrument. Next, an example of a more relaxed activity is also described. Deadlines play a specific role in intense learning. The role of deadlines is described in activities regarding the preparation of Learning Studio presentations and products.

> Episode 1. Mind map construction
> A school teacher in the second Learning Studio (LS) prepared an assignment to construct a mind map of secondary school student learning. During the meeting the assignment started with making individual notes related to the opening question (explicating individual knowledge). The second step was the exchange of notes in small groups (generating shared insights). The third and last step was collecting the results of the small group in the structure of the mind map that was designed by the teacher (developing shared language). During the small group and plenary discussions, concepts and relationships from literature were introduced by individuals who had studied this literature before. One beginning school teacher made specific contributions by referring to her readings of literature. At several moments the coach played a specific role by focusing the discussion and identifying shared or underexplored themes. Time and space were available to discuss some of the complexities of learning, such as the role of emotions, the unpredictability of outcomes and paradoxes in processes. In the mind map structure on the wall, concepts and relationships gradually crystallized toward a model in an organic process of growth. Student motivation and autonomy received special attention. The plan grew to discuss the mind map with an expert from the university in the following week. In the meantime, LS members are reading literature related to the mind map topics. Literature is becoming meaningful for the LS members.

In this episode 1, the shared mind map is a product (a specification of the object) that promotes interdependency in the group as a community. The three-step procedure and the frame for the mind map function as tools. The roles of the leading teacher, the coach and the beginning teacher who did a lot of reading are functional forms of division of labor. Equal opportunities for participation and contribution by all subjects reflect the rules of the community. Collaboration, reflection, and feedback are prominently present in this episode. Collective learning is promoted by the interdependence in the group task, and is expressed in the appreciation of the product, and the intentions for further steps. Individual learning results from the collective learning and contributes to the collective learning. Codified knowledge from literature, explicated tacit knowledge and related emotions get connected during the three steps of the procedure in the mind map, and in the personal meanings attached to the mind map and the literature.

> Episode 2. Development of observation instrument
> All student teachers in the first Learning Studio (LS) developed classes in which deep learning by students was promoted. They made videos of these classes as data for the research theme of the LS. In this work session an observation scheme for the analysis of the videos was discussed. The observation scheme for deep learning was developed at one of the participating universities. The scheme was introduced by a student teacher from this university, and he also lead the discussion in the LS on this topic. The aim was to develop a shared understanding and application of this scheme. The video of the class of one student teacher was central. At the start the discussion focused on the teaching behavior of the student teacher and on the meanings of deep learning. Gradually the discussion shifted toward the identification and interpretation of the behavior of students in the classroom. The leading student teacher tried several times to focus the attention on this student behavior: "Focus on what you see, what you hear." The special role of the coach was to focus attention on questions regarding validity and reliability (specificity/sensitivity, intersubjectivity, focus on what students do instead of speculating on what students think, scope of instrument related to restricted scope of observed fragments). The additional information on the student teacher in the video, and the interventions of the leading student teacher and the coach were all helpful in constructing a satisfying observation scheme after several attempts. All participants were strongly involved in this assignment, and interactive reflection (critical questions, agreement, feedback) was intense.

In this episode, the object of developing pedagogics for deep learning by students is specified in the shared community goal of constructing an observation instrument for deep learning in classrooms. This goal promotes a strong interdependency within the community. A leading student teacher introduces two tools: an existing instrument and a procedure for testing and adapting this instrument. The roles of this student teacher, the coach, and the student teacher who prepared the video of her class, express a functional division of labor. As in episode 1, equal opportunities for participation and contribution by all subjects reflect the rules of the community. Collaboration, reflection, feedback, and experimenting are prominently present in this episode. Collective learning is promoted by the interdependence in the group task, and is expressed in the enthusiastic emotions accompanying the product and the intentions for further steps. Individual learning results from the collective learning and contributes to the collective learning. The original instrument and the procedure for testing and adaptation represent codified knowledge regarding deep learning in classrooms and its measurement. During the session tacit knowledge regarding deep learning and related emotions are explicated. In the several steps of the procedure both types of knowledge and related emotions get connected (1) in the resulting observation instrument, and

(2) in the personal meanings attached to the knowledge and systematic observation of deep learning.

> Activity 1. A relaxed "in between" activity
> Halfway through the morning program (as a sort of beak) the art history teacher presented one of his assignments for secondary school students. Reproductions of art works from older and recent years were passed to the Learning Studio participants, and each participant selected one reproduction. The task was to have a good look at the art work, and to think about one sentence that represented participants' thoughts and feelings about it. After a while the selected reproductions and the sentences were exchanged among the participants. This exchange was very pleasant, and an enthusiastic discussion followed about how secondary school students might work with this assignment. No shared conclusions or collective follow-up were formulated. But individual learning gains were overtly exchanged.

No shared product was aspired for during this activity. The goal was to participate in a pleasant and informative activity as a community. This resulted in low task interdependence, and strong group cohesion. Division of labor was restricted to the role of the leading teacher, who presented the assignment as a tool and the rules of the assignment. In this activity the main focus is on reflection and feedback. Collective learning resulted from the shared emotion of successful group building and the pleasure of being member of an inspiring community. Individual learning depended on the personal meanings attached to the assignment, and intentions to apply such an assignment with own students.

> Activity 2. Preparation of presentations and products
> Both Learning Studios prepared several presentations and products for the plenary inspiration days (5 Learning Studios from different regions). During the preparation, deadlines played an important role. On the one hand, deadlines created pressure, which conflicts with the experience of room for inquiry, reflections and exchange. On the other hand, the deadlines functioned like high-pressure vessels, and as such they promoted collective result-directed work. This pressure function was positively appreciated by the participants.

The goal was the preparation of joint presentations of products and learning results for other related activity systems (Learning Studios, universities and schools). This activity was directly related to objects of the activity systems of schools and universities. Strong interdependency was promoted by this external expectation, and by the internal drive to show the best of what had been achieved by the community. These expectations and drives combined in the pressure of the deadline for the presentation. Collaboration, reflection, feedback, and experimenting are prominently present in this activity. Collective learning regarded the shared experience of the successful products and developing insights of the community, combined with feelings if pride and excitement about the achievements.

Group Dynamic Characteristics

We found that mutual trust and respect was essential in the learning processes in the Learning Studios. The coach of the Learning Studios stressed the importance of what he called a "triangle": safety, equality and space/room. The roles of mutual trust and respect, collegial support, and social cohesion are illustrated by the following example of a student teacher whose pedagogical ideas diverged from the dominant ideas in the Learning Studio.

> Episode 3. Discussing tensions
> In the second half of the first Learning Studio (LS) group interview one student teacher started talking about her positioning in the LS. For her, the open-ended start-up of the LS was hard to handle, because she missed personal vision, and expectations and knowledge for herself. There was no program and no clear goal. She preferred working toward a well-defined end product. She conformed to the situation: "I did not want to be the sorehead all the time." This tension regarded the functioning of the LS, as well as the "progressive" pedagogies that were central in many of the LS activities. She positioned herself as more traditional. She felt uncertain at such moments, so she kept her mouth shut. At the same time she appreciated the open climate in the group, and the mutual respect. It was important for her to maintain the safe climate, and she felt at home among nice people. During the interview team members' reactions were respectful, and questions were asked to get a better understanding of her position. This part of the interview was ended with a remark by one of the school teachers. He stressed that the LS should not be focused on progressive pedagogies. The LS is about better education for the students in the schools. The experience is that secondary school students can also show resistance toward new pedagogics. All LS members agreed with this reflection. Afterwards the coach of the LS explained that this tension also played a role in the relationship between this student teacher and her mentor teacher, who also participated in the LS.

This episode shows the essential role of mutual trust and respect, and at the same time it shows that these characteristics are not self-evident. They have to be repeatedly enacted by all members of the community. The student teacher only was open about her position in the group after a while during the group interview. In the reactions of the group members respectful collegial support was prominently present, which made it easier for the student teacher to clarify her position in more detail. This episode shows that for all the members of the community it is important to create and maintain group cohesion. Mutual trust and respect, collegial support, and social cohesion are important aspects of rules and community in the activity system. Moreover, episode 3 shows the role of appreciation for diversity. The word 'sharing' does not imply uniformity in beliefs and practices.

Professional Orientation

In the definition of the PLC characteristic "professional orientation" the word "shared" is often used. However, in the Learning Studios, which functioned as homogeneous teams, the visions and orientations could differ, leading to specific positioning of participants. The participants developed shared responsibility for learning from and with each other, *as well as* for student learning in schools, and they acted accordingly. The shared focus on student learning meant that the participants were permanently focused on improving student learning. However,

participants might differ in their ideas about what could count as an improvement, and how this could be realized in schools.

Steering Instruments

Three steering instruments for PLCs were distinguished: leadership, autonomy, and facilitation. Inside the Learning Studios, the coach played a significant leading role. In addition, there was shared leadership by all participants. Specific leading roles such as session chair were alternated.

As regards autonomy, room was created for self-directed steering within the Learning Studios. This created space for participants' question-directed learning, instead of steering by a program or curriculum. For school teachers in the Learning Studios this autonomy was experienced as protected space and time for inquiry and reflection. This space and time was found to be lacking during daily work in school.

Schools supported teachers by protecting time for participation in the Learning Studios. Universities supported student teachers by creating space within the university programs, but this space varied between universities. Moreover, space was created or already present within the examination regulations. The locations for sessions alternated between schools and universities. Rooms and lunches were made available.

The What of Learning in the Learning Studios

The results of expansive learning form a triplet. The expansive character of learning is in the *combined* occurrence of the three outcomes: (a) expanded pattern of action, (b) corresponding theoretical concept, and (c) new manifestations of participants' agency.

Expanded Pattern of Action

Several "materialized" outcomes of the Learning Studios were realized. Examples that are discussed in this article are the observation instrument, the mind map, and the presentations and products for general inspiration days. In addition, school teachers and student teachers developed new programs, materials and assignments for their students, with tryouts and evaluative discussions in the Learning Studios.

Corresponding Theoretical Concept: Familiarized Knowledge

Outside the Learning Studios, reading literature and listening to experts is tough work, and this is similar within the Learning Studios. However, within the Learning Studios, reading literature and discussions with experts encompass self-formulated questions, and that appeared to make a huge difference with learning in the universities and in the schools. Codified knowledge in literature and tacit knowledge in the schools interact in such a way that for all participants their learning expands into a productive mix. This is illustrated in the episodes 1 and 2 and the interpretations of these episodes.

This mix should not simply be interpreted as a bridge between codified and tacit knowledge. Rather, it is a qualitatively new type of knowledge, which we shall call "familiarized" knowledge. The content of this familiarized knowledge is not too different from the codified knowledge that is written down in literature. This resemblance is apparent in the content of the constructed mind map and the observation instrument. Also, it contains many insights and experiences that were already present in the school teachers' tacit knowledge. The difference is in the meaningfulness of this familiarized knowledge for the school teachers, the student teachers and the coach. According to the members of the second Learning Studio, the aim of this familiarized knowledge is not "to reinvent the wheel." The aim is to gain deeper insight into the wheel, and to make the wheel fit the own practice. Together this leads to familiarized knowledge owned by the participants of the Learning Studios. This is depicted in **Figure 1**.

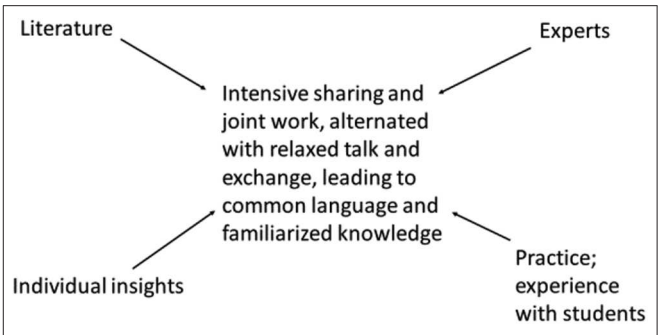

FIGURE 1 | "Familiarized knowledge" as an outcome of the Learning Studios.

The point of proposing familiarized knowledge as a new type of knowledge is that the implicitly present tacit knowledge has been explicated and shared, and that the published but abstract codified knowledge has been discussed from the viewpoint of daily insights and personal and shared experiences. Together this leads to explicit knowledge with a claim of intersubjectivity and validity, which makes it collective knowledge that is personally meaningful for every participant. It is familiarized because cognitive aspects go along with feelings/emotions of shared ownership and agency. Shared ownership can be understood in terms of the experience of practicality, mastery and intersubjectivity. Agency can be understood in terms of self-efficacy in designing inspiring and effective learning contexts for secondary students and for the members of the Learning Studio. The difference with tacit knowledge is that tacit knowledge is private and implicit, and it lacks the claim of validity and intersubjectivity. The difference with codified knowledge is that codified knowledge has a claim of general validity, and it lacks the personal feelings of shared ownership and agency.

The question can be asked as to whether this familiarized knowledge is produced continuously during all the LS sessions. This is not the case. The observations and interviews point in the direction of the most stimulating learning environment for the construction of familiarized knowledge when the participants engage in forms of joint work and intensive sharing. Stated in social psychology terms, these are situations characterized by a relatively high level of interdependency between the participants. Examples are the situations in which participants work on the "material" products that were described in episodes 1 and

2 and activity 2. Parts of all the sessions were devoted to more relaxed forms of exchange of experiences and materials, demonstrations of developed exercises for secondary students and tryouts for student teachers of designed classes. An example is activity 1. In those cases, it depended on what individual participants would take as meaningful information from those sessions for themselves. The resulting knowledge is personal and not systematically explicated.

With regard to the outcomes of learning, a tension occurs between individual and collective outcomes. Although familiarized knowledge can be regarded as a collective outcome, participants in the Learning Studios name their learning gains in terms of individual outcomes. In this respect they follow the image of collaboration as a *collective condition* for learning gains as *individual results*. Regular school culture and university culture both have a long tradition in representing the image of outcomes of learning and education as assets that are coupled with individual competences and qualifications, not as organizational gains. In workplace learning, on the other hand, it is not uncommon to aspire to organizational gains. The image of familiarized knowledge as a collective outcome better fits into the approaches of workplace learning.

New Manifestation of Agency

Learning Studios were constructed as learning environments by participants themselves, as agents of their own learning. The agency is in the enactment by the participants of the opportunities that are offered by the Learning Studios as their own learning environment. Episodes and activities show that this agency is combined with feelings of trust and respect, cohesion, and pride of the results. This is further elaborated in the discussion on the interrelatedness of the how and what of learning.

The Interrelatedness of the How and What of Learning in Learning Studios

We found that the process of learning and the outcomes of learning in the Learning Studios were interrelated in an extreme way. In their early stages in particular, Learning Studios had a double agenda, inventing themselves as learning communities and developing specific goals and a focus for the content of their work. This went together with meaty discussions around diverging opinions and uneasy feelings about the lack of direction and progress.

Interrelatedness was most apparent in the construction of the collective, familiarized knowledge described above. The outcome of familiarized knowledge cannot be separated from how participants learned, that is, the process in which this knowledge is constructed. In other words, learners only construct this type of knowledge when they are actively and collectively engaged in the kind of process that leads to this type of knowledge as a product. This is illustrated by episodes in two group interviews in which the interviewer asks the participants to be more explicit about the role of collaboration in their learning.

> Episodes 4 and 5. In both group interviews the interviewer asked the participants to be more explicit about the role of collaboration in their learning. The answers of the participants in both interviews illuminate three interrelated aspects: (1) how their collaboration helped their learning, (2) what they learned about collaboration in learning processes, and (3) how this differs from the learning of students in schools, and the learning of student teachers in universities. In the second group interview participants connect the role of autonomy in student motivation with their own autonomy as learners in the Learning Studio.

The members of the Learning Studios observe a striking difference between learning in the Studios and learning in schools and universities. The how and what of learning in the Learning Studios are related in a specific way, and autonomy plays an important role in this relationship. Besides the roles of intensive sharing and self-directed inquiring, an explanation for this interrelatedness might be the connection that is made in the process between cognitive and emotional aspects of knowledge, which is typical for familiarized knowledge. The interrelatedness between how and what differs from the traditional unilateral view in which the how (condition) and what (result) of learning are strictly separated. The results of this study suggest that the interrelatedness between how and what is a necessary context for the construction of familiarized knowledge. This context is mainly created by the participants themselves, and supported by the larger learning context. In this context emerging opportunities are created by the participants for the connection between cognition and emotion, that was identified in the episodes 1–2 and activity 2.

The Role of Contradictions and Tensions

Several sources of contradictions and tensions are identified in the course of the above presentation of results:

- Focus on tradition/conservation and focus on change/innovation (episode 3)
- Role of codified knowledge and role of tacit knowledge (episodes 1 and 2; activity 1)
- Individual outcomes and collective or organizational outcomes (episodes 1 and 2; activity 2)
- Self-directed learning and teacher-/curriculum-steered learning (episode 4 and 5)
- Images and pedagogies of workplace learning and traditional "school" learning (all episodes and activities).

These contradictions and tensions can be partly understood as resulting from differences between secondary schools and universities as diverging educational institutions. Moreover, these contradictions arise as tensions between the Learning Studios as a third space on the one hand, and the schools and universities as educational institutions with longstanding traditions on the other.

The role of these contradictions and tensions will be further elaborated in the discussion section as this appeared to serve as a source of explanation for the absence of dissemination and spin-off for schools and universities described in the next section.

What Outcomes of Learning Studios Affected the Activity Systems of University and School?

The importance of organizational outcomes for schools and universities of the Learning Studios as a result of snowballing is stressed by these partners in the network. Learning Studio participants visited schools, interviewed students and had conversations with school leaders. Nevertheless, for them, individual outcomes counted the most. Organizational outcomes in universities and schools, as a result of activities in the Learning Studios, were hardly identified during these 2 years. The few changes in schools or universities that were found were due to the efforts of individual participants within their own institutional environment (i.e., school or university).

A tension we discussed earlier might play a role here. This is the tension between individual and organizational outcomes. In the curricula for secondary school students and for university students, the qualification of these students as individual learners is the exclusive goal. In this respect, school and university cultures both have a long tradition in representing the image of outcomes of learning and education as assets that are coupled with individual qualifications and competences, not as organizational gains. This means that participants in the Learning Studios do not automatically take outcomes beyond the individual ones into account.

In addition, participants stressed the important role of question-based self-directed activities. Autonomy and agency played central roles in the Learning Studios. The question can be asked as to how much room for this question-based self-steering of learning was present and experienced by teachers and tutors when they "returned" to their school or university.

An observation, based on insights in discourse analysis, was made by the coach who stressed differences in communication practices between university or school on the one hand, and the Learning Studio on the other. The Learning Studios' communication practices developed into exploratory talk where, for example, roles changed from teacher to learner, and back. Communication in school and university was often characterized as recitation from teacher to student and the initiation (teacher)-response (student)-evaluation (teacher) pattern of teacher-student communication (Mercer, 1995; Nystrand et al., 1997).

DISCUSSION

In this concluding section, we discuss how the expansive learning and activity theory insights into contradictions and tensions contribute to explaining the processes and outcomes in Learning Studios and the school-university network. Firstly, the results are summarized by means of the elements of the activity system. Secondly, the finding that hardly any snowballing occurs from the learning outcomes of Learning Studios to universities and schools is discussed.

Learning Studios as Activity Systems

Results show that a variety of objects of the Learning Studios were realized. Participants succeeded in developing student-centered and innovative approaches to teaching and learning in secondary schools, in which the learning of the secondary school student was central. Moreover, professional development of both student teachers and secondary school teachers was realized. Student teachers in the Learning Studio developed toward becoming qualified and well-educated teachers in secondary education, and they succeeded in connecting the theory and practice of teaching by participation in the Learning Studio. School teachers in the Learning Studio connected their own practices to theory and research, and in doing so, they deepened insights into their own practices. Moreover, they improved their own teaching practices by designing and exploring new study tasks and courses/classes for students.

The Learning Studio communities consisted of an effective mix of subjects: student teachers, school teachers/mentor teachers and a university tutor as coach. The division of labor turned out to be dynamic, which was realized by alternating the roles of teacher and learner in every subject. The rules that focused on practices of equality in participation, openness, space, safety, and trust played central roles here. As a mediating tool, both Learning Studios developed a common program of single sessions, with alternating intense and relaxed forms of inquiry, in which uncertainty on the part of the participants was regarded as a source for learning. The program for a session demonstrated a variety of activities, exercises and assignments (**Appendix 1** in Supplementary Material).

The expansive learning was expressed in a triplet of related outcomes:

1. Several new methods for student learning were developed, tested and discussed;
2. "Familiarized knowledge" was developed, as a synthesis of tacit knowledge (from the school activity system) and codified knowledge (from the university activity system);
3. Agentic actions by the participants themselves resulted in (re)invented and (re)interpreted functioning of the Learning Studios as a new type of learning environment.

The PLC characteristics and steering instruments were helpful in describing the processes of learning in the Learning Studios as activity systems. However, this PLC framework deviates from activity theory regarding the roles of sharing and contradictions. In the PLC framework the focus is on sharing as a source for learning. In activity theory attention is also paid to how the activity system deals with contradictions and tensions in expansive learning.

Moreover, as well as intensive sharing, more relaxed forms of collaboration like exchange also played their roles in the Learning Studios. Interdependence between participants in dealing with contradictions and tensions was essential in the production of what we came to refer to as "familiarized knowledge." This relates to insights from studies about teacher inquiry and creative collectives. The distinction between intense and relaxed episodes of learning in the Learning Studio sessions is related to variants of teacher inquiry in PLCs that were identified by Dana and Yendol-Silva (2003). In "parallel inquiry," Dana and Yendol-Silva claim that every participant works on individual themes, but that connections between participants in the PLC are created, for example, through peer feedback. In "shared inquiry," participants

explore a shared theme together. Finally, in "intersecting inquiry," each participant explores a shared theme in her or his own way. "Shared inquiry" can be associated with the intense collective learning in the Learning Studios, and "parallel inquiry" relates to its relaxed learning episodes. "Intersecting inquiry" was neither observed nor reported in both Learning Studios. "Shared inquiry" was central in the construction of familiarized knowledge by the participants, but alternation with exchange and "parallel inquiry" was essential.

Shared inquiry learning environments offer opportunities for Learning Studios as creative collectives. In creative collectives, participants with diverging knowledge backgrounds, skills and experiences interact to find solutions for "wicked" problems (e.g., Hargadon and Bechky, 2006). These solutions could never be found and practically realized by single participants based on their individual competences and expertise. Typical activities of creative collectives include: asking each other for help, giving each other help, reflectively redefining a problem and potential solutions. These activities, which were observed during intense collaboration, are reinforced by progress made in problem solving, and by the shared experience of this progress.

Schools and Universities as Activity Systems

In a general way, Learning Studios appeared to contribute to 'objects' of universities and schools (delivering well-qualified teachers and educating qualified secondary school teachers). But looking more closely, the Learning Studios did not contribute to objects of schools and universities in the network in a way that added to the objects of both activity systems separately. The Learning Studios were only incidentally helpful in making minor improvements to the school and university programs and education. No structural snowballing was observed or reported.

First, strong connections between the Learning Studios and the communities of schools and universities were not realized. Connections and exchanges only resulted from individual relations between Learning Studio subjects and individual university and school subjects (e.g., other school teachers or other teacher educators). Second, the majority of teachers in schools and universities were not focused on the transmission of LS results. And third, in terms of rules and mediating tools, we identified several contradictions within both activity systems and between both activity systems and the Learning Studios activity system.

Why Did Snowballing From LS to Schools and Universities Only Occur Incidentally?

Learning in the Learning Studios was experienced as being very enriching by the participants themselves. Nevertheless, the outcomes and products of expansive learning within the Learning Studios appeared to be difficult to disseminate to schools and universities that participated in the larger network. This seems to be a paradox: When the results are so promising, why are the results of this learning so hard to disseminate from the activity system of the Learning Studio as a third space to the two larger activity systems that come together in the Learning Studios?

Part of the explanation for this paradox might be found in the familiarized character of the knowledge that was constructed. This "familiarized knowledge" can be characterized by the connectedness of the cognitive aspects of codified knowledge on the one hand, and the emotional aspects of ownership and agency that are important in daily teaching practice and in teachers' professional identity on the other.

Another part of the explanation might be that this familiarized knowledge is constructed in such a way that the content and the process of learning are always interrelated. In this interrelated process, cognition and emotion are closely connected. This connectedness, so typical for learning the Learning Studios, is not automatically or frequently present in regular learning processes in schools and universities. In learning codified knowledge (in universities), the what and how of learning are often analytically separated. Tacit knowledge (present in schools) is often constructed around assumed practical if-then relationships. For this reason, both codified and tacit knowledge assume an instrumental image of transfer from outcomes. Both assume that outcomes of Learning Studios can be disseminated 1:1 to universities and schools. But in this assumption, the interrelatedness of the what and how is neglected, and the connectedness between cognition and emotion is overlooked. In addition, the emphasis on individual qualifications in the educational culture might be underestimated while aiming for an organizational impact.

If the outcomes of the Learning Studios would be transferred 1:1 to the university learning environment and the secondary school learning environments, the familiarized knowledge of the Learning Studios would at best become a variant of the codified knowledge that is already well-known by teachers in both institutes. In this codified knowledge, the how and the what of learning are analytically separated, and cognitive aspects of knowledge are stressed. No connection is made with teachers' tacit knowledge. Disseminated this way, the recipients in schools and universities would not make the connection with the emotional aspect of familiarized knowledge, related to ownership and agency. As a result, there is no direct snowballing.

Opportunities for Snowballing

Expansive learning toward schools and universities outside the Learning Studios might be promoted by creating *similar learning environments within the schools and universities*, in which similar processes of constructing familiarized knowledge take place. In such learning environments, the specific mix of cognitions and emotions in familiarized knowledge can be constructed by participants in a process in which the what and how of learning are interrelated, and in which all participants are focused on realizing organizational gains in addition to individual outcomes.

Based on the results of this study, we propose the following characteristics of Learning Studio-like learning environments in universities and secondary schools:

- The community of learners includes groups that are both stable and mixed;
- Professional coaching as well as shared leadership;
- Sessions are protected by regular time and space;
- Autonomy because of self-directed learning with question steering instead of curriculum-/teacher-directed learning;
- Space for agency and diverse forms of inquiry;

- Orientation toward student learning in schools and universities;
- Appreciation of diversity and uncertainty among participants;
- Flexible programs and matching examinations in universities and schools;
- Practical and active participation of school and university leadership in efforts and discussions that promote dissemination and spin-off.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of Radboud Teachers Academy, Radboud University. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

JI collected the data, analyzed and discussed the data in relation to the theory, took the lead in writing parts of the theoretical framework, the analysis and results sections, and provided extensive feedback on the other parts. PM discussed the data in relation to the theory, took the lead in writing the introduction, parts of the theoretical framework, the discussion, and provided extensive feedback on the other parts. EB provided extensive feedback on, in particular, the results section and the episodes included there, on the Appendix about the day-to-day routine of the Learning Studios, and on all other parts of the texts.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2020.00064/full#supplementary-material

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