Impact of Physical Computing on Learner Motivation

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ABSTRACT

Intrinsic motivation is a key element of successful and effective learning. In computer science lessons, some students lack this kind of motivation. Physical computing requires learner initiative and activity, places high demands on their skills for self-determined learning and appeals to different senses. These characteristics suggest that physical computing activities are suitable for promoting intrinsic motivation. With the aim of investigating motivational aspects of physical computing activities in different classroom settings, questionnaire data from students are evaluated both as a whole and in comparison with each other. A short scale of intrinsic motivation was adapted and used in this cross-sectional study. The data was evaluated and compared to qualitative data from the same classrooms (e. g. gathered in learner reports or teacher interviews) to identify sources for success or failure with regard to the aims. Overall, physical computing activities result in higher motivational values than the average of any other activities in computer science classroom, especially when integrating suggested design principles for physical computing lessons that particularly focus on promoting creative and constructionist learning.

CCS CONCEPTS

• **Social and professional topics → K-12 education**;

KEYWORDS

CS education, physical computing, intrinsic motivation

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1 INTRODUCTION

We currently experience the third wave of digitalization: After the introduction and popularization of computers (first wave) and the Internet (second wave), *Ubiquitous Computing* nowadays is commonplace thanks to appropriate technologies [11]. Today, far more than 98% of all microprocessors are integrated in technical devices and everyday products [1]. We live in the digital world—a place where "information is available almost anywhere at almost any time, computer power is ubiquitous, communication of vast amounts of information is almost instantaneous" [4]. As Brinda and Diethelm put it, "Digital change, which affects our entire society, culture and economy, is shaped by people who are qualified in computer science, persons who have either completed vocational training or a university degree in computer science or who have acquired such competencies by themselves." [3]. Computer science (CS) education thus plays a crucial role in the digital networked world, a fact that is recognized by more and more countries and reflected in the development of school curricula and the introduction of appropriate school subjects either as elective courses, but often also as compulsory subjects, which students have to take no matter whether they are interested in it or not. Accordingly, didactically prepared learning environments are often developed with the aim of providing motivational and activating lessons that enthuse all students regardless of their specific background. Many tools for CS education offer opportunities for students to learn in motivating ways and gain impressive results, for instance in creating games and animations (e. g. Scratch or Greenfoot), developing smartphone apps (e. g. AppInventor), implementing 3D models (e. g. Beetleblocks) or developing interactive objects and smart devices with physical computing platforms (e. g. Arduino, BBC micro:bit).

Physical computing covers the design and realization of interactive objects and installations and allows learners to develop concrete, tangible products of the real world, which arise from their imagination. This can be used in computer science education to provide learners with interesting and motivating access to the different topic areas of the subject in creative learning environments [15]. Haptic experience is regarded as important by educators. Earlier investigations have shown, that for most teachers the dominant aims of physical computing teaching are of a pedagogic nature and include motivating students, raising interest, arousing curiosity among girls or showing that CS is a creative subject. Thus, physical computing is often chosen as a motivating context for acquiring and applying CS competencies. Some teachers use physical computing as enjoyable final projects, in which students need to transfer their knowledge from other teaching units and apply it in an attractive context [20, 18].

Evaluations of physical computing interventions often report positive motivational effects based on qualitative data about teacher or learner impressions (e. g. [7, 26]), but so far no larger-scale study was presented that reports quantitative data about students' intrinsic motivation in physical computing projects. Thus, the aim of this paper is to investigate the impact of physical computing on intrinsic motivation of learners using a standardized test instrument.

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2 BACKGROUND AND RELATED WORK

2.1 Physical Computing

Physical computing involves *creative arts and design processes* and, by bringing together *hard- and software components*, connects the virtual world of computers to the physical world of humans. Products of physical computing make use of *sensors* and *actuators* to interact steadily with their environment. Typical tools used for physical computing include *microcontrollers* and *mini computers*. In CS education, physical computing can be defined as follows:

> **Definition:** Physical computing is the creative design and realization of interactive objects or installations, which are programmed, tangible artifacts that communicate with their environment using sensors and actuators. In physical computing, many methods and concepts of embedded systems, cyber-physical systems and robotics are used.

In contrast to attempts that mainly deal with embedded systems in rebuilding or imitating existing products, e. g. robots, physical computing emphasizes a greater involvement of aspects of art and design, which opens up a wider range of opportunities to become creative. Physical computing further allows students to develop concrete, tangible products of the real world, which arise from their imagination. This way, students gain haptic experience and thereby abstract and virtual artifacts of learning are concretized.

2.2 Constructionism

It seems to be a special gratification for students to control real, physical objects, an aspect which is reflected in the learning theory of constructionism [14]. The pedagogical idea behind constructionism can be applied in particular to the creation of interactive artifacts in computer science education. With reference to Piaget's constructivism, learning is understood as the formation of knowledge structures by integrating new impressions gained from the environment with existing ideas and conceptualizations. In contrast to constructivism, the philosophy of constructionism considers learning most effective when learners are consciously engaged in constructing a public entity, be it a sandcastle on the beach or a theory of the universe [14, p. 1]. Resnick further explains: "What's important is that they are engaged in creating something that is meaningful to themselves or to others around them" [21, p. 281].

Papert [13] contrasts constructionism with instructionism. In his view, instructional learning is nothing more than listening to explanations, whereas constructionist learning means that knowledge is obtained on the learner's own initiative and for a personally relevant purpose [13, pp. 20f.]. This view implies that constructionist learning is possible only when the learner is intrinsically motivated.

2.3 Intrinsic Motivation

From the constructionist philosophy it can be deduced that intrinsic as opposed to extrinsic motivation is a basic requirement for sustainable learning. When a person is intrinsically motivated, he or she deals with a topic of his or her own interest, because the solution of the problem fulfills a personally relevant purpose for the motivated person. In computer science education some students lack this kind of motivation because the current subject matter at that point in time seems remote from reality and meaningless and is of little importance for the learner (see [10, p. 131]). Therefore, in school, situations must be created that relate to the interests of the students in the classroom and thus gives them the opportunity to recognize the relevance of the current problem. Ryan and Deci argue that choices and the ability to self-regulate learning reinforce intrinsic motivation, as they require greater learner autonomy [25, p. 59]. For school contexts, this means that teachers should allow students as much freedom as possible to avoid exposing them to a constant sense of control. However, it would be presumptuous to assume that it is possible to design a project or curriculum that would equally motivate all students intrinsically, especially since school environments usually do not provide the necessary framework: various field studies and experiments show that nearly any promised reward, but also threat (such as bad grades), deadlines, instructions or competitive pressures and thus typical means of extrinsic motivation, tend to suppress intrinsic motivation [25, p. 59]. In addition, intrinsic motivation can only occur if an activity intrinsically interests the students. Nevertheless, existing intrinsic motivation can be maintained and possibly strengthened by skillful action of the teacher.

2.4 Intrinsic Motivation in Physical Computing

Physical computing requires learner initiative and activity, places high demands on their skills for self-determined learning and appeals to different senses. Imagination and creativity are fostered in the process of creating interactive objects and systems. Children and young adults—similar to making a vase in pottery class—may bring home from school digital, interactive artifacts they themselves have created and programmed. These artifacts can be explored, shown around and admired in a constructionist sense. Based on this understanding, CS becomes personally relevant for students. All these characteristics suggest that physical computing activities are suitable for promoting intrinsic motivation, which is reflected in many teaching scenarios that aim for motivating students and reports that reflect on the motivational effects of physical computing lessons.

Kaloti-Hallak et. al [8], for example, investigate the effects of robotics activities on student motivation using selected and adapted questionnaire items from the "Science Motivation Questionnaire", which measures general academic motivation. Sentance et. al [26] analyze teacher and student interviews and identify positive motivational effects of physical computing activities around the BBC micro:bit. Also other works, including our own, focus on qualitative approaches of data capturing and evaluation and gain similar impressions (e. g. [7] and [20, 18]). A systematic evaluation of subject specific action-based intrinsic motivation in physical computing lessons compared to other CS lessons, however, so far is missing.

3 OBJECTIVES OF THE STUDY

Earlier investigations indicated that physical computing has high potential to motivate students, especially those who are not usually interested in computer science topics [19]. Therefore, the study presented in this paper has the goal to investigate learner motivation in physical computing activities in more detail and particularly in comparison to other activities in CS classrooms. For this purpose,

Table 1: Overview of the courses, the respective school, teacher, grade level and number of students (N) in the study.

course	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
school	S1	S2	S3	S4	S5	S5	S5	S5	S5	S5	S5
teacher	T1	T2	T3	T4	T5	T5	T6	T7	T6	T5	T8
grade	12	10	8	10	7	7	9	9	9	9	9
N	14	4	11	9	30	30	12	21	20	22	20

the learners' intrinsic motivation is measured and evaluated, e. g. depending on gender, age or computer affinity. Questions related to this objective are:

- How strongly are students intrinsically motivated by physical computing compared to other CS activities?
- Which elements of physical computing teaching promote intrinsic motivation?
- Which groups of learners benefit most from physical computing in terms of intrinsic motivation?

4 METHODOLOGY

4.1 Settings and Participants in the Study

This study was conducted over a time span of four years, starting with a preliminary study in two courses in the first year. In the preliminary study, a physical computing project was conducted during the school year 2014/15 in a divided elective CS course in a tenth grade of a high school in Berlin [19].

The main study was conducted in eleven different courses taught by eight teachers in five schools (table 1). The large majority of those courses were implemented in high schools in Berlin (90%). About 67% of the students were male. This distribution is very similar to the percentage of boys and girls in upper secondary CS courses in Germany[1] and result from the fact that CS is not a compulsory subject in most schools. Most of the involved schools were of the German school type Gymnasium, which focuses on the preparation of students for academic learning (84%). The majority of the courses were held in lower secondary levels, most often in grade nine (44.4%). It is noteworthy that half of the courses were conducted at the same school, which entails that 67.6% of the participants in this study visit the same school.

The average CS grades of the students' last school reports was 1.94[2], in maths the average grade was 2.46. The good results in CS can probably be explained by the fact that the data collected stems mostly from compulsory elective courses and thus it can be assumed that the students have a general interest in the subject.

The participating teachers were recruited in professional development workshops where they were introduced to the main ideas of physical computing, educational background information and possible scenarios for teaching (cf. [17]). In detail, they were introduced to design principles for physical computing that build on the work of O'Sullivan and Igoe [12], Rusk et al. [24] and our own classroom experience and aim at incorporating creative, constructionist learning to support student motivation:

(1) integrate tinkering activities in dedicated learning phases in which content knowledge and skills are acquired
(2) let learners create their own interactive objects ("pottery making approach")
(3) provide interesting themes: open topics that trigger imagination and creativity
(4) integrate creative methods
(5) integrate technical aspects with art/crafting
(6) provide scaffolds to structure the process of project work:
  (a) planning from user perspective
  (b) planning from developer perspective (non-technical and technical point of view)
(7) choose suitable construction kits and programming environments for the target group (low floors, wide walls, high ceilings)
(8) provide suitable crafting material and tools for the intended projects
(9) prepare a joint exhibition of all interactive objects
(10) present the results to an audience

4.2 Data Collection

Questionnaires are very time-economic means of data acquisition and are perceived as more anonymous and thus deliver more reliable data than personal interviews [2]. This study was therefore designed as a pre-post intervention study with two questionnaires, one prior to and one after the intervention in each learning group. While the first questionnaire was identical for most students (exceptions are explained below), the post-questionnaire contained sections that varied depending on the research goals within the respective group of learners. This way, it was possible to gain both, comparable data from a large number of students in various settings and detailed, qualitative data for the concrete settings that could be evaluated separately.

4.2.1 Demogaphic Data and Initial Situation. The first part of the pretest collects demographic data including gender, age and visited CS classes. The second part of the questionnaire contains ten items to investigate students' perceptions of their CS classes in terms of constructionist learning, creativity, fun and interest. These are used to capture the initial situation in the respective courses and are not repeated in the posttest because they refer to CS education in general. The development of this question set in a pre-study is described in detail in [16].

4.2.2 Intrinsic Motivation. Both, the pre- and post questionnaire, contain an adapted version of a short scale of intrinsic motivation (KIM, [28]), which is a standardized test instrument for learner motivation based on Ryan and Deci's self-determination theory [25] and the related *Intrinsic Motivation Inventory*[3] with the subscales interest/enjoyment, perceived freedom of choice, perceived competence and pressure/tension. The subscale interest/enjoyment delivers self-reported values of intrinsic motivation, while perceived freedom

[1]Figures according to unpublished statistics of the German Standing Conference of the Ministers of Education and Cultural Affairs (KMK), which were provided to the author of this article on request.
[2]In the German school system, grades range from 1 to 6 (1=very good, 2=good, 3=satisfactory, 4=sufficient, 5=poor, 6=unsatisfactory).

[3]http://selfdeterminationtheory.org/intrinsic-motivation-inventory/

of choice and competence are positive predictors for intrinsic motivation. Pressure and tension is a negative predictor of intrinsic motivation indicating a lack of autonomy and self-determination. The KIM test was already successfully used in CS education research, for example in the comparative analysis of programming courses in groups using different tools [23].

Wilde et al. [28] show that this scale is suitable for making time-stable, objective, reliable and valid statements concerning students' intrinsic motivation in out-of-school-learning and in contexts where self-determined and competent actions are in focus, which mostly is the case in open and action-oriented classroom situations. In this particular research project, where interventions take place in regular classrooms, KIM is preferred over other measurement instruments (e. g. [22, 5, 6]) because it is very time-economic, which is particularly important as the KIM is part of a larger questionnaire. Furthermore, it measures action-based intrinsic motivation rather than more general academic intrinsic motivation and thus gives information about motivation with respect to physical computing activities, not to the subject in general. The original test items of this scale were adapted for the purpose of the study ("in the exhibition" was replaced by "in the lessons"). This procedure is recommended by the authors of the KIM and should not affect the informative value of the test items, of which a translated version is listed below:

- interest/enjoyment
  (1) The lessons were fun for me.
  (2) I think the lessons were very interesting.
  (3) The lessons were enjoyable.
- perceived competence
  (4) I am satisfied with my performance in the lessons.
  (5) In the activity in the lessons I did a clever job.
  (6) I think that I was pretty good at the activity in the lessons.
- perceived choice
  (7) I could control the activity in the lessons myself.
  (8) I could choose how I do the activity in the lessons.
  (9) During the activity in the lessons I could proceed the way I wanted.
- pressure/tension
  (10) During the activity in the lessons I felt pressured.
  (11) During the activity in the lessons I felt tense.
  (12) I was concerned if I could do the activity in the lessons well.

The twelve items of the KIM are captured with a five-level Likert scale (0–strongly disagree, 1–disagree, 2–neither agree nor disagree, 3–agree, 4–strongly agree) and evaluated as such. Thus, the mean values for each item lie between 0 and 4 and for each subscale between 0 and 12. For all subscales except pressure/tension, higher values report higher intrinsic motivation or predictors of such. To estimate the overall motivational values in this study, the results of the subscales interest/enjoyment, perceived competence and perceived freedom of choice are summed up and the result of the subscale pressure/tension is subtracted. Thus, in total, a maximum value of 36 can be gained in the test.

As the KIM was reviewed and evaluated by the authors of the scale, it was included in the study without further testing. Its validity was confirmed and it was shown that the four subscales have sufficient internal consistencies and were test-retest reliable [28]. For the evaluation it is important to consider that the time of the measurement can influence the result: Although the test results from the same group at different measurement times strongly correlate with each other, measurements with a clear temporal distance to the intervention are rated lower in the subscales *interest/enjoyment* and *perceived freedom of choice* than directly after the intervention. The subscale *pressure/tension* was less reliable and valid in the scale evaluation, therefore results in this domain need to be interpreted carefully [28].

4.2.3 Expectations and Opinions. Further questionnaire items capture students' expectations of CS education in school and their opinions about the extent of the learning matter, difficulty and personal knowledge gains in the previous lesson series (regardless of the topic), which are also included in the posttest, to compare the results to the physical computing unit. Most of the posttest questionnaires also contained short versions of learner reports (cf. [27]) to gain qualitative feedback in order to be able to estimate reasons for observed effects.

4.3 Evaluation

Overall, based on the data captured with the questionnaires comparisons could be drawn in the following domains:

- intrinsic motivation, including the subscales *interest/enjoyment*, *perceived competence*, *perceived freedom of choice* and *pressure/tension*
- perceived extent of the learning matter, difficulty and personal knowledge gains
- self-rated abilities in terms of CS and physical computing

For different reasons, in a few cases it was only possible to distribute a single questionnaire, which combines the pre- and the post-questionnaires and was handed to the students after the intervention. It covers only those areas where no pre-post-comparison is made. In this paper, the main focus lies on the motivational effects of physical computing; the other aspects are only examined to gain additional information if necessary.

4.4 Subsamples

For the evaluation of the data, the students are clustered in different subsamples. The data are analyzed for differences in the pre-post-evaluation for *all students*, *boys vs. girls* and *insiders vs. outsiders*. Insiders in terms of computer use, as described by Knobelsdorf [9], are computer-savvy students who perceive CS contents in school as useful to expand their knowledge and helpful for solving problems. They see computers as tools for creative programming, administration and exploring hardware. Outsiders in terms of computer use rather have aversions to computers and perceive CS contents in school as useless, incomprehensible or nebulous. They see computers as useful but arbitrarily acting devices [9]. Thus, their intrinsic motivation for learning in CS is often low.

With the help of questionnaire items based on Knobelsdorf's findings, learners who perceive themselves as insiders or outsiders concerning their computer experience were identified. For this purpose, first of all the student data concerning their handling of occurring PC problems was evaluated and so, a first rough classification was made. Then, their expectations of CS education, their

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assessment of previous lessons, own skills and capabilities and their behavior regarding computer use were analyzed. This information was used to verify and possibly correct the initial clustering. The classification always took place in one go, meaning that all students were assigned to one group. If students could not clearly be assigned as either insider or outsider, they were set back for the time being and considered again at the end. In order not to falsify results, students who finally could not be clearly assigned to insiders or outsiders were sorted into a third category "unknown". This procedure was repeated in four iterations, each time several days apart. This increased the objectivity of the classification, as all students were considered multiple times and as impartial as possible[4]. Inter-coder-reliability was tested on about 30% of the data with two additional coders. As there were only few discrepancies, it is assumed that especially through the multiple iterations, the majority of students were correctly classified according to the predetermined categorization. The following examples represent typical student answers for outsiders in terms of computer use:

- "[I use my computer] to do research for school, watch movies and series and surf the web."
- "I expect after taking this course I can handle my computer better."
- "I think I don't have the capabilities to develop an interactive computing system."

Exemplary answers of insiders in terms of computer use include:

- "[I use my computer for] 3D modeling and writing my own scripts"
- "I want to seriously learn programming with languages like Java."
- "I think I can develop an interactive computing system on my own."

5 PRELIMINARY STUDY

In order to generate hypotheses for the evaluation of the motivation data in the main study, in the preliminary study the questionnaire was evaluated for physical computing lesson series that were given by the first author of this article in team teaching with a local teacher in two groups of the same class (cf. [19]). Prior to the physical computing intervention, all students were introduced to basics of programming using the block-based programming language Scratch. As the two groups were taught one after the other, they had different preconditions concerning their programming experience. While the first group learned in the physical computing project, the second group was introduced to the programming language Python and vice versa.

In both groups, for all students alike *increased intrinsic motivation* was found for the physical computing activities in general, but especially on the subscale *perceived freedom of choice*. Students who were classified as outsiders were substantially lower motivated in the pretest compared to their classmates who were categorized as insiders. Although there still is a gap between those values in the posttests, indicators were found that suggest that outsiders in terms of computer use seem to benefit more from the project than insiders, i. e. that they showed higher intrinsic motivation gains in physical computing activities, than those who were already interested in the subject. Thus, the gap between those two groups narrows. Similar results were observed for girls and boys. These effects are particularly visible on the subscale *perceived competence*. In the second group especially the girls and, less distinct, outsiders showed more *interest and enjoyment* in the physical computing lessons, while boys' and insiders' interest and enjoyment values decreased in comparison to the prior lesson series.

Despite some differences in the individual subscales, findings from the first course were mostly confirmed by the second group. Significance tests using the repeated measures t-test with $\alpha = .05$ in both gropus show that most of the results are not significant, which means that it cannot completely be ruled out that the results are effects of randomness. Exceptions are the results for the total score and scores on the subscale *perceived freedom of choice* in some of the subsamples. The results are still used to generate hypotheses, since it can be assumed that they gain significance when larger data sets are evaluated:

H_1 Physical computing is an intrinsically motivating activity for students.

H_2 In terms of intrinsic motivation, outsiders benefit more from physical computing activities than insiders.

H_3 In terms of intrinsic motivation, girls benefit more from physical computing activities than boys.

6 MAIN STUDY

In general, most students liked the projects: 133 of the 193 participants (69%) said that they would like to do a physical computing project again, 45 students (23%) negated this question and another 15 (8%) abstained. From the items of the short scale of intrinsic motivation, which is explained and evaluated in detail below, conclusions can be drawn, among other things, about the students' interest in the topic and fun during the lessons (fig. 1). On average, all items showed higher values in the posttest, indicating that in the physical computing activities, students had more fun, were more interested and entertained, slightly more satisfied with their performance, and especially had more choices and learned more self-determined and according to their own wills than in the lesson series prior to the physical computing unit. This is particularly impressive in that the initial situation in most courses was already very positive. However, on average they also felt a little more pressure and tension and were more concerned if they would do a good job. The following evaluation will show how this affects the overall intrinsic motivation of the students, which groups of learners benefit most from physical computing and if the results are statistically significant.

6.1 Analysis

The purpose of the main study was to test the hypotheses concerning student motivation derived from the earlier studies. It was expected that in the overall data the observed effects from the small student groups are clearly visible, that the results average and—through the higher number of participants—gain significance. The sample of the main study was composed as follows: $N_{total} = 193, N_{female} = 71, N_{male} = 122, N_{insiders} = 84, N_{outsiders} = 82$. To avoid misinterpretations based on errors

[4]This method was developed and applied as part of a master thesis supervised by the first author of this paper.

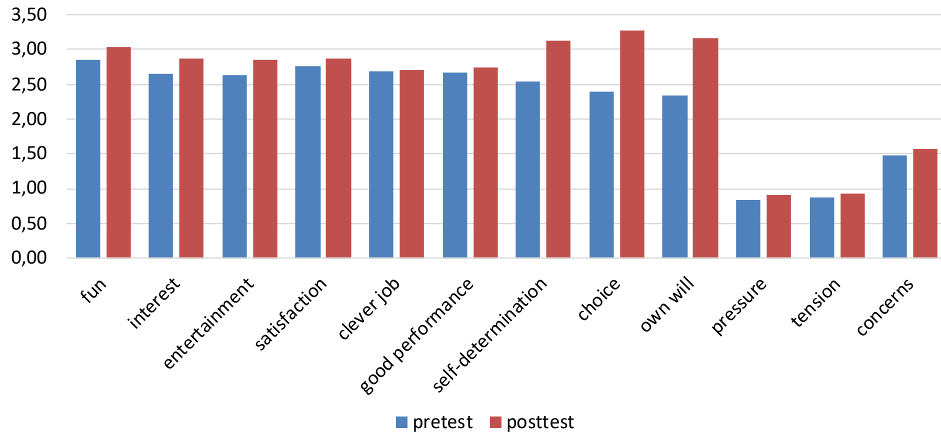

Figure 1: Items of the short scale of intrinsic motivation ([28]) in pre-post comparison (interval $[0, 4]$).

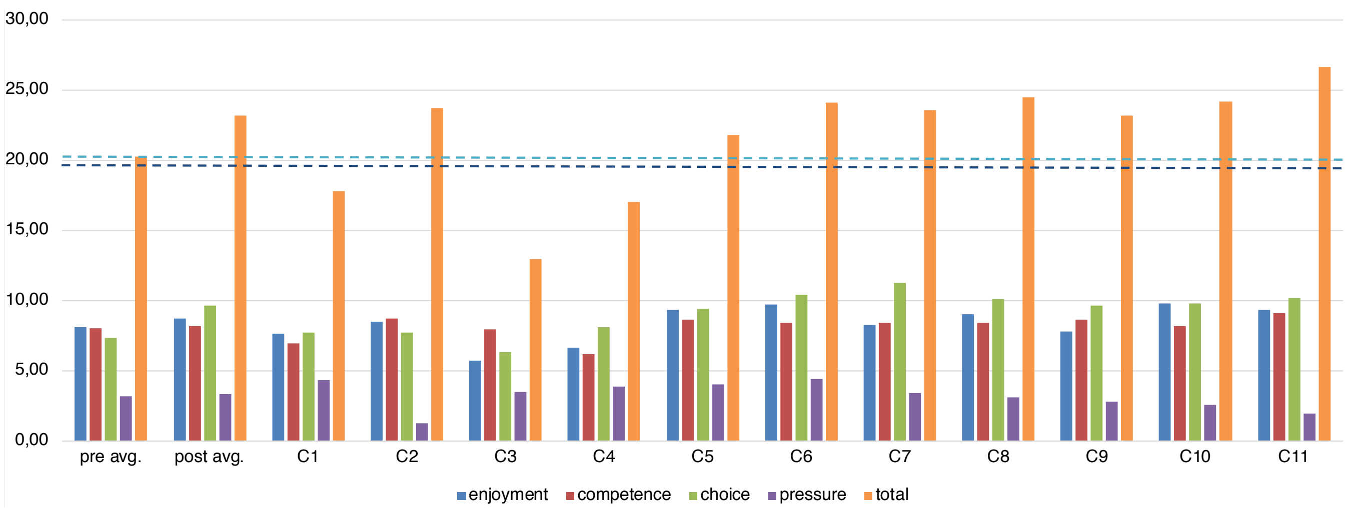

Figure 2: Posttest values for all schools (different subscales, interval $[0, 12]$ and total motivation, interval $[0, 36]$) compared to average pretest values (dashed lines, light blue: cleansed data set, dark blue: shifted average for all students).

because of different preconditions, the available data is evaluated both, in total and for the different subsamples. First, pre-post comparisons are made on the whole corpus. Then, subsamples are investigated and used to assess the acceptability of the above-mentioned hypotheses. Finally, conspicuous results are examined in more detail and possible causes are investigated with the help of qualitative data.

With ten different courses of which data is available from pretests ($N_{students} = 189$), data of a variety of topics in the directly preceding lesson series is available: programming in block-based and textual environments, making a movie about potentials and dangers of the Internet, binary representation of data, web design with HTML, and several more. The posttest always refers to physical computing lessons. Thus, from the pretests, average motivational values for CS education in secondary schools are calculated and from the posttest average values for physical computing lessons for the same target group are gained.

For pre-post comparisons, data where only post-questionnaires were available had to be eliminated (C1, C2, C4), which resulted in the following cleansed sample of the corpus: $N_{total} = 163$, $N_{female} = 64$, $N_{male} = 99$, $N_{insiders} = 63$, $N_{outsiders} = 79$. As shown in table 2, the value differences between the complete and the cleansed data set are small (about .3 in an interval of $[0, 12]$ on the subscales), but shift the results of the overall motivation by .6 (in the interval $[0, 36]$), which needs to be taken into account during the evaluation. Thus, for groups where only posttest data is available, the pretest averages from the other groups are shifted by $-.6$ and used for comparison (fig. 2). However, actual pre-post comparisons with significance tests can only be drawn in those courses, where data is available from both tests (cleansed data set).

6.2 Results

First, it is noticeable that in all but one course, student motivation was higher after the physical computing activities compared to the

Table 2: Pre-post comparison of values of the different subscales (interval [0, 12]) and total motivation (interval [0, 36]) for all students and cleansed data.

	all data			cleansed data		
	pre	*post*	*diff.*	*pre*	*post*	*diff.*
enjoyment	8.11	8.69	0.58	8.10	8.99	0.89
competence	8.02	8.19	0.17	8.10	8.54	0.44
choice	7.30	9.64	2.33	7.25	9.87	2.62
pressure	3.21	3.33	0.12	3.10	3.38	0.28
total	20.23	23.19	2.96	20.39	23.94	3.55

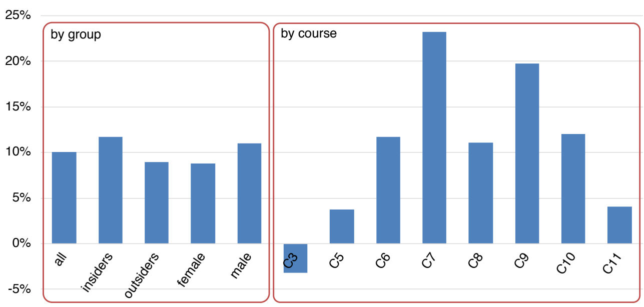

Figure 3: Change in overall motivation (pre-post) for all students and the different subsamples (interval [0, 36]).

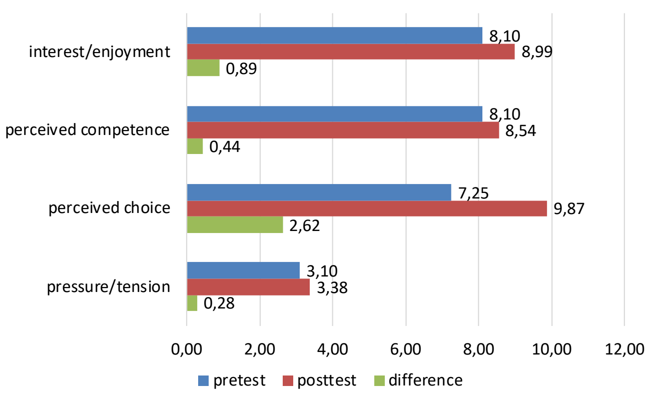

Figure 4: Pre-post comparison of values of the different subscales (interval [0, 12]).

preceding lesson series (cleansed data, fig. 3). This is true for all subscales (fig. 4), also for the construct *pressure/tension*, which is a negative predictor. The dimensions *interest/enjoyment*, *perceived competence* and *perceived freedom of choice* show statistically significant effects in relation to physical computing teaching. In contrast, the results prove to be not statistically significant in the construct *pressure/tension*. The corresponding values for all subscales and their effect sizes are listed in table 3.

6.2.1 Testing H_1: "Physical computing is a highly intrinsically motivating activity for students." In order to test this hypothesis, first it must be defined how *high* intrinsic motivation can be measured over *good* or *low* intrinsic motivation. For this purpose it is assumed, that high is more than average, meaning that a significantly higher total value of average learner motivation in physical computing projects should be measured compared to average intrinsic motivation of students in any other topic of CS.

Table 3: Results of repeated measures t-test (right-tailed) for null hypothesis significance testing ($df = 156$). Asterisks indicate significance level.

	enjoyment	competence	choice	pressure	total
t	4.120***	2.077*	10.627***	1.368	5.608***
p	< .001	.02	< .001	.087	< .001
d	.666	.333	1.702	.219	.898

In fig. 2 it can clearly be seen that on average and in 73% of the analyzed courses, the physical computing activities result in higher motivational values than the average of any other classroom activities. For more accurate comparison and to determine if the results are significant, the cleansed data is used. A repeated measures t-test (right-tail) is used for null hypothesis significance testing. As usual in such analyses, a threshold value of $\alpha = .05$ is assumed to identify significant, $\alpha = .01$ very significant and $\alpha = .001$ highly significant results. The null hypothesis and alternative hypothesis are set to:

H_0 = "Physical computing does not influence students' intrinsic motivation"
H_a = "Physical computing increases students' intrinsic motivation".

It can be reported that on average, participants showed higher intrinsic motivation after physical computing activities ($M_{post} = 23.94$, $SE = 0.48$) than after any other classroom activity in CS ($M_{pre} = 20.39$, $SE = 0.67$). This difference ($M_{dif} = 3.55$, $SE = 0.63$, increase by 17, 41%) is highly significant ($t(156) = 5.608$, $p < .001$) and represents a large-sized effect ($d = .898$). Thus, H_0 can be rejected, the alternative hypotheses is accepted and it can be assumed with very high probability (> 99.999%) that the results are not due to chance and that there actually is a measurable effect. Therefore, in conclusion, H_1 can be accepted.

6.2.2 Testing H_2: "In terms of intrinsic motivation, outsiders benefit more from physical computing activities than insiders." As shown in table 4, in contrast to the expectations, the data does not confirm the hypothesis from the preliminary study. Both groups show higher motivational values in the posttest and the motivational gap even increases slightly. Insiders showed higher intrinsic motivation gains between random CS learning scenarios and physical computing activities than outsiders ($M_{insiders} = 4.06$, $SE = .98$, increase by 18.86%; $M_{outsiders} = 3.30$, $SE = 0.99$, increase by 17.33%). These results are highly significant (H_0 and H_a as before; $t_{insiders}(61) = 4.125$, $p < .001$; $t_{outsiders}(73) = 3.337$, $p < .001$) and represent large-sized effects ($d_{insiders} = 1.056$, $td_{outsiders} = .781$). In conclusion, H_2 must be rejected.

6.2.3 Testing H_3: "In terms of intrinsic motivation, girls benefit more from physical computing activities than boys." Similar to the results of investigating H_2, the observations from earlier studies were not confirmed in the larger data set. Again, both of the investigated

Table 4: Pre-post comparison of values of the different subscales (interval $[0, 12]$) and total motivation (interval $[0, 36]$) for insiders and outsiders in terms of computer use.

test	subscale	outsiders	insiders	diff.
pre	enjoyment	7.89	8.38	0.49
	competence	7.81	8.36	0.55
	choice	7.02	7.35	0.33
	pressure	3.71	2.64	-1.07
	total	18.98	21.35	2.37
post	enjoyment	8.64	8.89	0.25
	competence	7.69	8.98	1.29
	choice	9.49	9.66	0.17
	pressure	4.10	2.95	-1.15
	total	21.72	24.5	2.78

Table 5: Pre-post comparison of values of the different subscales (interval $[0, 12]$) and total motivation (interval $[0, 36]$) for girls and boys.

test	subscale	boys	girls	diff.
pre	enjoyment	8.05	8.23	.18
	competence	8.18	7.97	-.21
	choice	7.07	7.52	.45
	pressure	2.82	3.66	.84
	total	20.24	19.93	-.31
post	enjoyment	8.80	8.76	-.04
	competence	8.66	7.81	-.85
	choice	9.37	10.03	.66
	pressure	3.01	4.07	1.06
	total	23.55	22.42	-1.13

groups show higher motivational values in the posttest and the motivational gap between those groups increases slightly. Boys showed higher intrinsic motivation gains between random CS learning scenarios and physical computing activities than girls ($M_{male} = 3.87$, $SE = .88$, increase by 18.70%; $M_{female} = 3.09$, $SE = 0.89$, increase by 15.50%). These results are highly significant (H_0 and H_a as before; $t_{male}(92) = 4.400$, $p < .001$; $t_{female}(62) = 3.474$, $p < .001$) and represent large-sized effects ($d_{male} = .918$, $d_{female} = .882$). A course-wise analysis of this issue revealed that only in three of the courses, girls showed higher gains in comparison to the preceding lesson series than boys (C8, C9, C11). In conclusion, thus, H_3 must be rejected, too.

6.3 Interpretation and Discussion

In this section, the results presented above are interpreted with regard to the research questions. Additional (qualitative) data are evaluated if necessary to understand detected phenomena.

6.3.1 RQ1: Motivational value in physical computing activities compared to other CS classroom activities. The analysis results clearly show that physical computing has the potential to intrinsically motivate learners more than many other activities in CS classrooms, independent of the concrete setting. Moreover, in the large majority of courses, the students' intrinsic motivation to engage in the project was higher than in the preceding lesson series given by the same teacher and independent of the topic.

Thus, physical computing is a very motivating context than can be used in CS education to provide students with opportunities for sustainable learning in which they acquire problem-oriented knowledge, skills and competencies to solve problems they have chosen for a personally relevant purpose. It is the teacher's job to skillfully create learning environments in which the study of the intended learning content becomes necessary.

6.3.2 RQ2: Motivation promoting elements of physical computing teaching. To investigate the question, which elements of physical computing are particularly successful for motivating students, those courses with very high or low motivation gains are analyzed in more detail.

In course C3, in which motivation decreased in comparison to the prior learning unit, students of an eighth grade with initial programming experience in Scratch were introduced to physical computing with Makey Makey. They did some research on the Internet about possible projects with these tools, before starting their own. The teacher reported problems with this very heterogeneous class. He mentioned two students who are very talented but were bored with these projects, especially as the creative potential of the tools is not very large in his opinion. Many of the students reportedly were overwhelmed with the constructions and some of them were clumsy at making things. All in all, the teacher perceived the lessons as long-drawn and also the students' learner reports illustrate boredom and a lot of frustration, as some students were unsatisfied with—in their opinion—unjustified bad grading.

In the other courses, the high values in the dimension *perceived freedom of choice* are particularly striking. These may be explained by the mostly project-like nature of the implementations, in which learners pursue their own ideas, often without strict requirements regarding the project procedures. It is surprising to see that values in the dimension of *pressure/tension* increased. Although these results are not statistically significant, it is worth considering possible explanations: It is conceivable that many students are not used to work in projects and therefore struggle with timely project completion, which might lead to pressure and tension. Observations and learner reports show that in physical computing, students have to cope with hurdles that are beyond what they are used to from other situations in CS classes, e. g. related to debugging hardware, crafting and constructing things. This might evoke a feeling of skepticism concerning possible project completion and thus pressure and tension. When analyzing the learner reports of all those students whose total motivation decreased ($N = 45$), some aspects occurred frequently that may have influenced their motivation:

- project completion (62.2%): Many students reported success or frustration depending on whether they completed their projects or not
- programming (15.6%): programming was often perceived as difficult especially for beginners; students frequently showed desire for more detailed explanations
- debugging (13.3%): it was hard for some students to find mistakes in their program code and correct them
- creativity and invention (13.3%): many students said it was hard to be creative, find ideas and implement them

- technology (8.9%): technical hurdles were perceived as annoying
- grading (8.9%): students reported frustration with bad grades as well as pride with good grades
- patience and endurance (8.9%): the projects demanded students to be patient and persistent, which was new for some of them

Less frequent factors included teamwork (6.7%), concentration (4.4%), teacher, material and unreachable goals (2.2% each).

When looking in particular at the upper positions in this list, it becomes obvious that the implementation of projects in CS classrooms often gives students the freedom of choice, but also puts them under pressure. Therefore, methods of project work should also be used in regular lessons, so that in larger projects students are not faced with insurmountable hurdles. In general, the influence of project work and suitable methods on learner motivation in physical computing and CS education in general should be investigated more closely.

The list also shows that programming is difficult for students, especially for beginners. This is not a new phenomenon and influences CS teaching in general. One of the relevant aspects seems to be debugging: in such open settings as most of the physical computing projects, students can not rely on the teacher or classmates working on the same tasks: They each struggle with their particular problems and need to find ways to solve them. This can be both, motivating and frustrating, depending on the success or failure with the particular problem solution. Thus, targeted and purposeful debugging should be a subject of instruction in CS teaching.

Another critical aspect is that of creativity: while some students enjoyed being creative in class, others found it very hard to come up with ideas and creative implementations. Therefore, promoting creativity in the classroom, e. g. using aspects of design thinking or other creative methods and supporting constructionist learning environments are important aspects of physical computing teaching that should also be emphasized more strongly in CS education in general.

6.3.3 RQ3: Influence of physical computing depending on gender and computer affinity. A closer look at the courses C8, C9 and C11, which were the only courses in which girls showed higher motivation gains than boys, showed that all of those courses were implementations of the school project "My Interactive Garden" (MyIG) [15]. MyIG is an exemplary approach to integrate physical computing in computer science teaching. It is based on a constructionist learning environment, which allows CS students to craft, design, program and build their own interactive objects. The learners use their imagination and creativity in order to develop personally relevant interactive objects using microcontroller based construction kits (e. g. MyIG Toolbox[5], Arduino Tinkerkit[6]) with preassembled sensors and actuators and a shield that allows plugging in the components easily. The aim of learning with MyIG is to collaboratively create an exhibition of interactive objects as they could be found in a futuristic interactive garden. Such objects can be anything from magic flowers to noisy scarecrows to interactive party lights. This framework allows for multiple and manifold projects and is supposed to trigger students' creativity. MyIG emphasizes the design principles for physical computing mentioned in section 4.1 and thus aims at incorporating creative, constructionist learning to support student motivation. It includes learning phases were pupils decidedly learn and acquire specific concepts and skills[7].

Table 6: Gender distribution of insiders and outsiders (cleansed data set, $N_{total} = 163$, $N_{male} = 99$, $N_{female} = 64$).

affinity	# (%) male	# (%) female
insiders	49 (49%)	14 (22%)
outsiders	41 (41%)	38 (59%)
unknown	9 (9%)	12 (19%)

The general comparison of courses that used MyIG with other courses showed that MyIG implementations proved better for appealing to female students, which was one of the teachers' main intentions. In 71% of the courses (including those that were taught by the author of this article), girls showed larger motivation gains than boys, which are highly significant and represent large-sized effects in both groups (girls: $M_{dif} = 6.17$, $SE = 1.21$, increase by 35.20%, $t(38) = 4.132$, $p < .001$, $d = 1.341$; boys: $M_{dif} = 3.55$, $SE = .884$, increase by 16.46%, $t(79) = 3.846$, $p < .001$, $d = .862$). This was not achieved with any of the other implementations. The reasons for this can only be speculated about; however it is very clear that MyIG strictly adheres to the proposed guidelines and particularly provides a context that is interesting for most students (cf. [16]).

Reflecting the results of the investigation of the hypotheses H_2 and H_3, the similarity between the values of boys/insiders and girls/outsiders is striking. This may be explained by large overlaps between those groups, as shown in table 6. Gender distribution is, although not evenly distributed, reciprocal to computer affinity. Therefore, the one aspect might also influence the other and it cannot be said with certainty, if gender, computer affinity or both are the relevant parameters in this investigation.

6.4 Deeper Investigations and Additional Findings

As many of the teachers who participated in this study were familiar with MyIG from professional development workshops, some of them adopted this project for their teaching, so that in total about half of the students learned in MyIG-settings (all students: $N_{MyIG} = 95$, $N_{notMyIG} = 98$, cleansed data set: $N_{MyIG} = 94$, $N_{notMyIG} = 69$). A closer investigation revealed that the MyIG courses are also the courses with the highest total scores.

When looking at the different subsamples in more detail, it was noticeable that the MyIG implementations on average show motivation values more than twice as high as general physical computing activities. This is also visible in the posttest results of all courses (including single test courses), where in particular three groups stand out with average values below pretest average (fig. 2). In all three courses, the teachers decided for different learning scenarios than MyIG and adapted the material or developed their own. These

[5] http://tangible-cs.de
[6] https://github.com/Tinkerkit
[7] The MyIG material is available for download at http://tangible-cs.de

courses differ from the others in that they do not consequently implement the proposed physical computing design principles.

In course C1, for example, the students were required to develop necessary skills on their own and without any specially prepared materials, which made it particularly difficult for them to use the MyIG toolbox. Also in the planning of their projects there was no scaffold, their task simply was to develop an idea and implement it. In course C4, the opposite was the case: The teacher narrowly guided his students during the activities and gave many explanations, as he considered this approach to be appropriate for the specific learning group at an "Integrierte Sekundarschule"[8]. Interestingly, the students of this course on average had the lowest mean values in the dimension *perceived competence*. Again, the students were not guided during the project phase despite that they should find an idea first and start working afterwards and some of the student works resulted in "wild" projects without a deeper meaning.

In both courses, C1 and C4, a textual programming language was used. Unfortunately, from those courses only single questionnaires are available, so that no actual pre-post comparison is possible.

7 SUMMARY AND CONCLUSION

Overall, physical computing has proven to be a motivating classroom activity in all courses that adhered to the proposed guidelines, which were often MyIG implementations (62.5%). Not all of the initial assumptions and hypothesis were confirmed during the analysis and possible reasons for the lack of success of single implementations were discussed with reference to teacher statements and students' learner reports.

Concerning the effectiveness of the chosen approaches towards the teachers' goals, most courses succeeded. In the data, high motivational values are found especially concerning the students' perceived level of choice, as most teachers implemented physical computing in project work where the learners defined their own goals, sometimes based on certain requirements, and approaches towards fulfilling these goals. In relation to their perceived competence after the course, better results are gained when emphasizing self-directed learning instead of step-by-step explanations and too narrow guidance, but also providing suitable learning resources instead of general research tasks; this finding, however, should be further investigated, as based on the available data it can not be confirmed because there are too few classes that followed an approach of narrow guidance.

Concerning motivational aspects, some courses were identified that were less successful than the average. They all had in common that they deviate strongly from the proposed design principles, which specifically aim at incorporating creative, constructionist learning and at supporting student motivation; thus it can be concluded that promoting creative and constructionist learning in class is critical for the success of physical computing activities.

REFERENCES

[1] BITKOM. 2010. Eingebettete Systeme – Ein strategisches Wachstumsfeld für Deutschland. (2010). https://www.bitkom.org/noindex/Publikationen/2010/Leitfaden/Eingebettete-Systeme-Anwendungsbeispiele-Zahlen-und-Trends/EingebetteteSysteme-web.pdf.

[2] Jürgen Bortz and Nicola Döring. 2005. *Forschungsmethoden und Evaluation: für Human- und Sozialwissenschaftler*. Springer-Verlag, Berlin Heidelberg.

[3] Torsten Brinda and Ira Diethelm. 2017. Education in the Digital Networked World. In *Tomorrow's Learning: Involving Everyone. Learning with and about Technologies and Computing*. Springer, Cham, 653–657.

[4] Walter Gander et al. 2013. Informatics Education: Europe Cannot Afford to Miss the Boat. Tech. rep. Informatics Europe & ACM Europe Working Group on Informatics Education. http://europe.acm.org/iereport/ACMandIEreport.pdf.

[5] Adele Eskeles Gottfried. 1985. Academic Intrinsic Motivation in Elementary and Junior High School Students. 77, 6, 631–645.

[6] Susan Harter. 1981. A new self-report scale of intrinsic versus extrinsic orientation in the classroom: Motivational and informational components. 17, 3, 300–312.

[7] Yasmin B. Kafai et al. 2014. A Crafts-Oriented Approach to Computing in High School: Introducing Computational Concepts, Practices, and Perspectives with Electronic Textiles. 14, 1, 1–20.

[8] Fatima Kaloti-Hallak et al. 2015. Students' Attitudes and Motivation During Robotics Activities. In *Proceedings of the Workshop in Primary and Secondary Computing Education* (WiPSCE '15). ACM, New York, NY, USA, 102–110.

[9] Maria Knobelsdorf. 2008. A Typology of CS Students' Preconditions for Learning. In *Proceedings of the 8th International Conference on Computing Education Research* (Koli '08). ACM, New York, NY, USA, 62–71.

[10] Maria Knobelsdorf. 2011. *Biographische Lern- und Bildungsprozesse im Handlungskontext der Computernutzung*. Ph.D. Dissertation. Freie Universität Berlin, Berlin.

[11] Christine Legner et al. 2017. Digitalization: Opportunity and Challenge for the Business and Information Systems Engineering Community. 59, 4, 301–308.

[12] Dan O'Sullivan and Tom Igoe. 2004. *Physical Computing: Sensing and Controlling the Physical World with Computers*. Thomson Course Technology PTR, Boston.

[13] Seymour Papert. 1980. *Mindstorms - Children, Computers, and Powerful Ideas*. Basic Books, Inc., New York.

[14] Seymour Papert and Idit Harel. 1991. Situating Constructionism. In *Constructionism*. Ablex Publishing Corporation, Norwood.

[15] Mareen Przybylla and Ralf Romeike. 2012. My Interactive Garden – A Constructionist Approach to Creative Learning with Interactive Installations in Computing Education. In *Constructionism 2012: Theory, Practice and Impact*. Ed. Tech. Lab, National Kapodistrian University of Athens, 395–404.

[16] Mareen Przybylla and Ralf Romeike. 2014. Overcoming Issues with Students' Perceptions of Informatics in Everyday Life and Education with Physical Computing - Suggestions for the Enrichment of Computer Science Classes. In *Proceedings of the 7th International Conference on Informatics in Schools: Situation, Evolution and Perspectives*. Ankara University Press, 9–20.

[17] Mareen Przybylla and Ralf Romeike. 2016. Teaching Computer Science Teachers – A Constructionist Approach to Professional Development on Physical Computing. In *Proceedings of Constructionism 2016*. Suksapattana Foundation, Bangkok, Thailand, 265–274.

[18] Mareen Przybylla and Ralf Romeike. 2017. The Nature of Physical Computing in Schools. In *Proceedings of the 17th Koli Calling International Conference on Computing Education Research, Koli, Finland*. ACM New York, NY, USA, 98–107.

[19] Mareen Przybylla et al. 2016. Bridging Motivation Gaps with Physical Computing in CS Education. In *International Conference on Informatics in Schools. ISSEP 2016. October 13 – 15, Münster, Germany. Proceedings*, 53.

[20] Mareen Przybylla et al. 2017. Teachers' Expectations and Experience in Physical Computing. In *International Conference on Informatics in Schools: Situation, Evolution, and Perspectives* (LNCS). Vol. 10696. Springer, Cham, 49–61.

[21] Mitchel Resnick. 1996. Distributed Constructionism. In *Proceedings of the 1996 International Conference on Learning Sciences* (ICLS '96). International Society of the Learning Sciences, 280–284.

[22] Falko Rheinberg et al. 2001. FAM: Ein Fragebogen zur Erfassung aktueller Motivation. *Diagnostica*, 47, 2, 57–66.

[23] Alexander Ruf et al. 2014. Scratch vs. Karel: Impact on Learning Outcomes and Motivation. In *Proceedings of the 9th Workshop in Primary and Secondary Computing Education* (WiPSCE '14). ACM, New York, NY, USA, 50–59.

[24] Natalie Rusk et al. 2008. New Pathways into Robotics: Strategies for Broadening Participation. 17, 1, 59–69.

[25] Richard M. Ryan and Edward L. Deci. 2000. Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. 25, 1, 54–67.

[26] Sue Sentance et al. 2017. "Creating Cool Stuff": Pupils' Experience of the BBC Micro:Bit. In *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education* (SIGCSE '17). ACM, New York, NY, USA, 531–536.

[27] Baukje J. Van Kesteren. 1993. Applications of De Groot's "learner report": A tool to identify educational objectives and learning experiences. 19, 1, 65–86.

[28] Matthias Wilde et al. 2009. Überprüfung einer Kurzskala intrinsischer Motivation (KIM) (Testing a short scale of intrinsic motivation). *Zeitschrift für Didaktik der Naturwissenschaften*, 15, 31–45.

[8] Secondary all-day schools in Berlin, grades seven to ten, degree confirms VET maturity, possible transfer to upper secondary level.