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Differences in Self-Directed Learning: Middle-School Students' Autonomous Outdoor Studying

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The use of self-directed learning (SDL) is an increasingly widespread trend in schools, although its core—the student's attentional capability for multi-level processing—to construct relevant concepts and at the same time to keep in mind the needed sub-items, while also directing one's own learning, has not been thoroughly investigated. We examined autonomous learning outdoors in small groups with 122 school students aged 14–16 years (the period that, through the developmental peculiarities of puberty, causes variety in cognitive skills). To detect whether individual characteristics reflect in students' SDL progress, we measured participants' pre-knowledge, their problem-solving strategies, and post-knowledge. We also asked about their prior SDL experience. The results showed 1) relations between one's pre-and post-knowledge levels; 2) the impact of gender in the SDL efficacy; 3) the difficulty to memorize in the course of complex tasks while learning on one's own. Our work gives insight into the SDL-specific heightened cognitive demand: school students' cognitive obstacles in heavy load conditions and their prolonged maturation of executive functions—especially in adolescence as this age group passes its normal biological spurts of the human developmental path—which may differ individually.

Keywords: self-directed learning (SDL), cognitive load (CL), cognitive executive abilities, individual differences in school students' SDL capacity, complex learning

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INTRODUCTION

Self-directed learning (SDL) that prevails in 21st-century education (Järvenoja et al., 2015) aimed at supporting students to make independent choices and form concepts is also defined as complex learning, in which learners in the course of their own inquiry solve problems in fruitful environments (Schwaighofer et al., 2017, p. 60). Although self-directed learners ought to find and process different information with deep-level thinking skills in order to reach relevant conclusions, they often lack an important prerequisite: domain-knowledge to make sense and memorize while processing the learning material (Butcher and Sumner, 2011).

The problem is that by using various types of knowledge (Hematian et al., 2017), while also self-instructing and controlling one's own learning (Zimmerman, 1989), SDL creates a considerably higher cognitive load to a learner compared to conventional learning methods (De Bruin and van Merriënboer, 2017). At the same time, there are considerable individual differences in the developmental maturity of the brain—the organ that enables one's cognitive ability—due to the structural differences in specific regions of the cortex (Blakemore, 2012, p. 8). Too high cognitive load, especially in case one has the immature cognitive capability for schema construction (Janssen et al., 2010), as a result, can only lead to shallow changes in new knowledge acquisition instead of deep learning (Butcher and Sumner, 2011). Another problem is that, although the SDL approach requires proper monitoring skills (which, if inaccurate, can jeopardize the learning progress), these kinds of metacognitive strategies are rarely taught (De Bruin and van Merriënboer, 2017).

The current work contributes to the area of SDL research on adolescent school students by investigating the relations of the participants' prior knowledge (within the topic), problem-solving strategies (during the current SDL assignment), based on findings that both of those skills together shape the prerequisites needed for complex learning (Schwaighofer et al., 2017), and gender aspects (Schweder and Raufelder, 2019). We also asked about the school students' previous SDL experience (before the current study) to find out their reflections on learning on their own, as the majority of studies in the SDL area have been carried out in adult education contexts (Schweder and Raufelder, 2021).

Theoretical Background

Although the SDL-specific skills—cognitive strategies, regulation, and evaluation of one's learning—are vital educational priorities (Hematian et al., 2017), significant individual differences have been found in school students' cognitive executive abilities to carry out those sub-acts (Best and Miller, 2010; Zelazo and Carlson, 2012). Students with more advanced executive control to resist distraction (Rutherford et al., 2018) have greater success with the SDL approach, while learners with weaker executive skills get more easily captured by automatic or "competing" responses when trying to retain the relevant information (Engle, 2018, p. 191). For example, poor impulse control leads to difficulties in generating or implementing proper strategies, which causes problems with planning, regulating, and monitoring one's performance and reduced working memory (Anderson, 2002, p. 72). Nonetheless, despite the learner's capability, the SDL-specific reasoning in order to reach a relevant conclusion (to make sense and relate the material to be memorized) requires skills 1) at the single object level and at the 2) overall meta level (De Bruin and van Merriënboer, 2017). This kind of complexity increases one's cognitive load (Janssen et al., 2010) that can hamper attention control (Best and Miller, 2010; Ecker et al., 2010) to keep the focus (Engle, 2018) in multiple switching between one's mental tasks (Miyake and Friedman, 2012). This, in turn, severely restricts the ability to direct one's own learning (Rutherford et al., 2018). As a result, solving complex problems is found to be difficult, especially for low-level executive capability learners (Halford et al., 2007; Nęcka and Lulewicz, 2016).

The latter is especially important in school-age students, whose executive abilities—attentional flexibility, inhibitory control, and WM (Best and Miller, 2010)—go through protracted development (Davidson et al., 2006; Nęcka and Lulewicz, 2016; Watson et al., 2016). Therefore, on the one hand, executive functions' efficacy (to orchestrate goal-directed mental acts, based on synchronous neuronal activity within the prefrontal cortex) directly depends on the varying developmental dynamics of the brain; on the other hand, "performance in more complex tasks does not fully mature until the age of adolescence and even early adulthood" (Best and Miller, 2010, p. 1641). It is because the frontal cortex (which supports complex processing described above) is the last area of the brain to mature along with a child's normal development (Anderson, 2002; Davidson et al., 2006; Lee et al., 2013).

Therefore, the SDL approach can cause cognitive overload for a large proportion of students who do not yet have fully matured cognitive capability (Nęcka and Lulewicz, 2016), which, as a result, can lead to inadequate or only superficial knowledge gain (Sweller et al., 2019). It is because executive attention, on the one hand, improves in the course of prolonged developmental paths, and on the other hand, by varying maturing speed of the latter (Rutherford et al., 2018), enables the student to avoid responding based on the first reaction (that comes to mind) and to act based on proper choices rather than impulsive acts to avoid premature or not relevant conclusions (Davidson et al., 2006; Miyake and Friedman, 2012).

The aforementioned aspects are important to address in the SDL approach, as the capacity of the human working memory to process new information (yet to be learned) tends to be limited (able to maintain only 4 ± 1 elements concurrently); thus, when a learning environment is too cognitively demanding, keeping the focus, in order to memorize, is hampered (Engle, 2018). Thus, effective schema construction in long-term memory will not occur (Janssen et al., 2010). Three main executive functions: updating (to add or delete contents of the working memory), inhibition (to resist impulsive or not proper responding), and shifting (to switch between one's mental sets of information) are all inevitably needed for flexibly operating with cognitive tasks (Miyake and Friedman, 2012; Schwaighofer et al., 2017) in order to handle only task-appropriate information for efficient task completion (Garner, 2009). Executive functions are therefore crucial, especially in SDL, enabling efficiency in sequential mental acts (one after another, as the SDL demands) that require only the relevant info-items and rules (at the time) to be kept in mind, while resisting distractions caused by irrelevant info-items or the interruption of those of the previous sets (Schwaighofer et al., 2017). However, despite the reciprocal findings, the importance of executive functions within the SDL paradigm is rarely described (Rutherford et al., 2018).

Self-Directed Learning and Developmental Differences in Adolescence

The prefrontal cortex plays the most important role in executive functions, while longitudinal studies have shown that around the age of 16 years, the frontal lobe significantly increases its white matter volume (through the myelination spurt, covering the axons), which fosters the rapidity in nerve-cell transmission, thus reducing the distance cost in neuronal networks (Uytun, 2018).

In other words, prefrontal cortex development (like human brain development in general) consists of progressive and regressive changes: myelination and synaptic pruning towards more sophisticated neuronal connections (Best and Miller, 2010, p. 1643). Increased connectivity thus facilitates synchronous impulses between neurons, providing a structural basis for more efficient cognitive functions; however, the final myelination process of the human frontal lobe can continue even into the 3rd decade of life (Uytun, 2018). Nonetheless, major reorganizational changes in the brain functional networks occur during adolescence, as interactions between different networks reduce and the within-network connectivity enhances, making the processing more “efficient” (Blakemore, 2012).

However, it has also been found that the late biological blooming of synapses in particular cell types and thus interrelationships within the prefrontal cortex that enable control functions directly depend on pubertal processes (Delevich et al., 2018). Hence, both children and adolescents (compared to adults) show weaker top-down signals from frontal areas, directly reflecting control function, in different tasks (Blakemore, 2012).

Self-Directed Learning and Gender Differences

In a review of recent research on the topic, Schweder and Raufelder (2019) have shown that multiple studies have found gender differences related to learning: adolescent girls (compared to boys of the same age) in general have greater willingness to put effort into learning, while boys evince fewer control strategies compared to girls. The latter is found to be related to the fact that, in terms of development, the maturation of the cognitive control advancement takes longer for boys than for girls (Weber et al., 2021). Girls are thought to suffer less from the influence on particular cerebral structure changes caused by the impact of testosterone on the cortical thickness and gray matter volume in the frontal lobes of the brain (Delevich et al., 2018).

Gender differences have also been found in students’ underlying learning strategies. According to Schweder and Raufelder (2019), girls, in particular, reflect and monitor their own learning progress more efficiently. At the same time, although boys tend to keep trying in the face of challenges (Liu, 2009), they evince fewer control functions than girls (Schweder and Raufelder, 2019). At the age of 15, girls, through the benefit of their more proper cortical thickness (compared to boys of the same age), have advantages in the brain regions that are responsible for the enhancement of working memory (Weber et al., 2021). Better working memory fosters more efficient joining of concepts (to solve problems) that may require combinations of different knowledge and strategies to be kept in mind, which is crucial in more complex tasks requiring the joining of several parts (Weber et al., 2021). Nevertheless, multicomponent tasks accompanying SDL can hamper executive control (Ecker et al., 2010), which, in turn, can restrict concentration on only relevant info-items in working memory to be processed and then saved as a bound-together sub-result in one’s long-term memory (Sweller et al., 1998). A contradiction has been found: while working memory is being used to search the sub-solutions, that is common in SDL, it is not used for good memorization (Kirschner et al., 2006).

Self-Directed Learning and Pre-Knowledge

Prior knowledge importance unfolds especially often in novice learners when their pre-knowledge in terms of sufficient associations between the elements as linking connections has not yet formed; thus, in case of less pre-knowledge, one’s cognitive mechanism gets even more taxed from the starting point of an SDL scenario by organizing the learning material into a coherent structure (Cowan, 2014). In doing so, the overly challenged executive functions are not able to resist non-relevant items interrupting the processing of currently relevant ones (Schwaighofer et al., 2017). At the same time, the inhibition, which allows one to resist irrelevant information, also needs substantial working memory contribution for an arbitrary rule (to estimate relevant or not?) to be held in mind (Archibald and Kerns, 1999). As a reciprocal advantage, proper resistance towards irrelevant information frees up additional capacity in working memory to deal with currently relevant information; thus, learners with efficient inhibition have fewer difficulties dealing with multicomponent problems (Schwaighofer et al., 2017, p. 62). Therefore, the ability to avoid attention capture either by internal thoughts (“... what’s for lunch today. . .?”) or external events (“... what a nice butterfly...”) (Engle, 2018, p. 191) forms the core of complex learning (Schwaighofer et al., 2017). For the same reason, children accused of “not trying hard enough to follow directions” are often those with low working memory and immature executive function and thus are not able to remember instructions, muster the resources, and/or pay attention (Cowan, 2014). Because those with poor attention control are weaker in concurrent processing (Unsworth et al., 2009) and in switching between the rules and sub-tasks (Rutherford et al., 2018), this can constrain their overall SDL progress (Zelazo and Carlson, 2012). However, the SDL approach is directly grounded on the simultaneous demand to hold “excerpted” information in mind while inhibiting other items, which is truly difficult as one’s mental settings must be continually reset when the task changes (Davidson et al., 2006). Therefore, the impact of learners’ pre-knowledge in SDL becomes especially important as it includes two components: 1) one’s factual prior knowledge within the learning topic (fostering online processing through one’s pre-links) and 2) proper domain skills, together shaping one’s prerequisites needed for complex learning (Schwaighofer et al., 2017).

The Current Study

Based on prior findings of the individual differences among adolescent students and the challenging cognitive load accompanying complex SDL (Schwaighofer et al., 2017), we were interested in how these variables interact during the SDL assignment, understood here as encompassing the following autonomous learning phases: gathering data, analyzing the data, and the learners making conceptual their own conclusions. We designed an outdoor SDL scenario in which the aim of the participants’ activity was to learn in a real-life (fruitful) environment. Our ultimate goal was to discover the relationship between aspects of individual characteristics (pre-knowledge level, problem-solving in the current SDL task, and one’s previous SDL experience) and SDL efficacy (gained in the current SDL task).

We used in this experiment the setting of small group learning. We followed prior social and developmental psychology findings, suggesting that students can learn better through interaction and discussions with their peers based on cognitive development theories by Vygotsky and Piaget, who both highlighted the importance of enhancement of the learning mechanisms during collaboration with others (where more capable learners can help/scaffold less capable learners in tasks they could not accomplish working individually) that promotes one's development of new cognitive schemas (cited by Janssen et al., 2010).

Aims and Hypothesis

First, we aimed to explore how the participants' conceptual understanding (within the learning topic) changed over their SDL scenario.

Second, we examined which strategies the participants implemented to solve the problems they faced during the SDL assignment outdoors. We compare the aforementioned aspects in two (although quite close but still different, considering adolescence age developmental spurts and individual differences in the given) age groups and by gender.

Third, we looked at the participants' retrospective reflections on their previous SDL experience by asking, "how do you usually feel about learning on your own?" To broaden our understanding of the executive cognitive aspects in school students within the SDL framework, we sought answers to our main research questions: 1) How do adolescent school students' individual characteristics relate to their SDL? 2) What type of subcategories appears in students' retrospective reflections on their usual SDL experience? The hypotheses are as follows.

H1: Pre-knowledge level has an impact on one's SDL gain.

Prior knowledge importance unfolds especially often in novice learners when sufficient associations between the elements as linking connections have not yet formed, thus taxing one's cognitive mechanism (Cowan, 2014) in resisting irrelevant information (Unsworth et al., 2009; Schwaighofer et al., 2017) and switching between the rules and sub-tasks (Rutherford et al., 2018), which constrains one's overall SDL progress (Zelazo and Carlson, 2012).

H2: Gender predicts students' knowledge gain efficacy in SDL.

Girls reflect and monitor their own learning progress more efficiently (Schweder and Raufelder (2019). At the age of 15 years, girls (compared to boys of the same age) gain the advantages in the brain regions that are responsible for the enhancement of the working memory, which fosters more efficient joining of concepts (to solve problems) and combining of different knowledge and strategies to be kept in mind (Weber et al., 2021). Compared to boys, girls are less influenced by the testosterone impact on the brain bio-structural changes (Delevich et al., 2018).

H3: There will appear differences in participants' problem-solving strategies (in the SDL outdoor assignment).

As the SDL-specific reasoning (to make sense of the material) requires skills at the single object level and meta level (De Bruin and van Merriënboer, 2017), it increases the cognitive load (Janssen et al., 2010) that hampers attention control (Best and Miller, 2010; Ecker et al., 2010) to keep the focus (Engle, 2018) on complex tasks (Miyake and Friedman, 2012). This severely restricts the ability to direct one's own learning (Rutherford et al., 2018) and solve problems, especially for the lower-level executive capability learners (Halford et al., 2007; Nęcka and Lulewicz, 2016).

H4: Participants' self-reflections on their prior SDL experience will reveal difficulties related to complex tasks (where the contribution of executive functions is needed).

The SDL approach requires advanced executive control to resist distraction (Rutherford et al., 2018) when trying to retain the relevant information in the focus of attention (Engle, 2018). However, immature impulse control leads to difficulties in implementing strategies and thus problems with planning, regulating, and monitoring one's own performance and reduced working memory to be kept in mind for processing (Anderson, 2002). The latter is especially important in school-age students, whose executive abilities, attentional and inhibitory control related to WM (Best and Miller, 2010), go through protracted development (Davidson et al., 2006; Nęcka and Lulewicz, 2016; Watson et al., 2016).

MATERIALS AND METHODS

Participants and Study Design

The participants in the study were adolescent school students between the ages of 14 and 16 (students in grade 8 were 14/15 years old and in grade 9 were 15/16 years old) in six classes from two municipal schools in Estonia. Our intention was not to separately study students from grade 8 and grade 9 in particular, but rather to use this age group from the perspective of developmental differences revealed more clearly among adolescents (as described above). Our aim was to explore the multicomponent aspects that facilitate the SDL approach through the sample of the given age range (who, on the one hand, are vulnerable to high cognitive load and, on the other hand, go through significant spurts in the brain maturing). By 1) comparing their pre- and post-knowledge in terms of the two conceptual levels (before and after), we can detect the efficacy of their learning process, i.e., as an outcome of the course of one's SDL regarding their progress. 2) Examining the SDL strategies that participants report they used in this outdoor learning lesson, we can see whether they need help in the course of their SDL scenario or do they cope on their own. 3) Asking their own reflections on their previous experience learning directed on their own (i.e., before the current SDL-lesson), we can find out the main difficulties while using the SDL approach.

Inclusion criteria. Although there was a larger group of students (250 participants altogether) taking part in this outdoor learning experiment, due to various technical reasons (for example, several students had not answered all the questions and/or did not provide their correct personal identification code in each sub-task, so some data was not usable), $n = 122$ was used for this analysis, including 62 boys and 60 girls.

This experiment was organized as a part of a more extensive study on innovative approaches to learning and teaching outside the classroom supported by mobile technology.

Research Instruments and Data Analysis

Semi-Structured Questionnaires on Participants' Conceptual Knowledge Level Within the Given Educational Domain

These were conducted 1) before and 2) after the experimental outdoor learning assignment. Participants' knowledge level change (gained in the latter) was coded according to the model introduced in Heddy et al. (2017), which shows operationalization of conceptual change to understand the participants' restructuring of conceptual knowledge about a certain phenomenon from a non-scientific view towards a scientific perspective:

"1" is an inaccurate conception; "2" is a hybrid conception (mixed misconceptions); "3" is an accurate but underdeveloped understanding (includes 1 explanation); "4" is an accurate but not perfectly developed understanding (2 explanations); "5" is a well-developed understanding (3 or more explanations). Cohen's kappa value between the two researchers' estimations on participants' conceptual knowledge levels was 0.894 (asymptotic standard error was 0.033; approximate Tb was 17.698; $p < 0.001$), which shows the validity was good (i.e., near-perfect agreement).

Semi-Structured Questionnaires on Participants' Retrospective Reflections on Their Previous Learning Experience Directed on Their Own

This was conducted before the outdoor learning task. To reflect on their own prior SDL experience, the participants were asked to choose one of the following options: "it is always difficult for me to learn on my own because attention gets distracted easily when too much information needs to be remembered at once"; "it is often difficult for me to switch from one task to another"; "it is usually not so difficult for me to learn on my own"; "it is sometimes difficult for me, especially with more complex tasks, because the necessary things are not remembered"; or "depending on how much information you need to remember at a time: if more, then harder; if less, then it is easier to learn on my own". Effect size on this by Cramer's V = 0.2825, $p < 0.05$ (p-value = 0.0230) showed a modest relationship.

Semi-Structured Questionnaires on How the Students Resolved the Difficulties Encountered During the Outdoor Task

This was conducted after the outdoor learning task. In order to understand how the students as a group resolved difficulties occurring during the experimental task, they were instructed to choose as many as applicable from the following list of options: "we did not face any problem"; "we ignored the problem and continued with our activities"; "we asked for help from the teacher"; "we asked for help from the other students"; and "we investigated on our own until we could resolve the problem." The answers in terms of their coping strategies re-coded as follows: 0) "without problems" (i.e., "we did not face any problem"); 1) "ignoring the problems" (i.e., "we ignored the problem and continued with our activities"); 2) "help-seeking" (i.e., "we asked for help from the teacher" and/or "we asked for help from the other students"; 3) "self-managing" ("we investigated on our own until we could resolve the problem.").

FIGURE 1 | The SDL data gathering activities outdoors.

The analysis was conducted using both SPSS and the r-Studio statistics program.

Procedure

The experiment started in the students' everyday classroom, where after a short introduction about the upcoming experiment and outdoor learning assignments, the participants individually filled a questionnaire on their 1) pre-knowledge and 2) on their prior SDL experience. The given two tasks lasted ~15 min. After that, participants were voluntarily divided into small groups (consisting of an average of three students to carry out SDL activities outdoors). Each group followed a predefined path with different location points for carrying out a variety of interdisciplinary learning activities, such as gathering and measuring data on the environmental situation (**Figure 1**), analyzing the collected data, and interpreting them to draw conclusions. Although the outdoor activities were performed within small groups (where all participants were asked to contribute equally), the final conceptual conclusions were made (and accomplished in the post-knowledge questionnaire) individually.

The learning topic in grade 8 was "how to differentiate plants" and in grade 9, the topic was "air quality around the school" (more precisely, environmental chemistry and bio-indicators). The outdoor activities lasted ~60 min. After participants finished their studying outdoors, they came back to the same classroom, where each participant individually fulfilled the questionnaire on

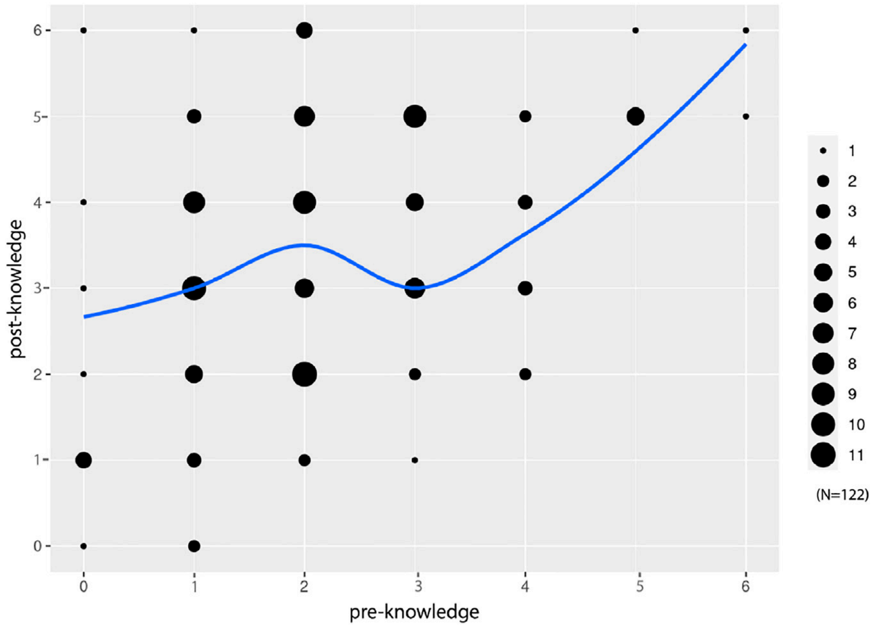

FIGURE 2 | Pre- and post-knowledge relation. The bigger the bullet in the graph, the more participants it covers. The blue line shows the trajectory of the correlation.

3) post-knowledge and 4) on how they resolved the difficulties encountered during their outdoor assignment. These tasks lasted ~15 min. The whole experiment lasted for two academic hours (2 × 45 min).

We were interested in two dimensions in this experiment: 1) participants' individual efficacy using this kind of SDL scenario and 2) characteristics that students highlight in their retrospective reflection on their previous SDL experience.

Permission was asked from the school director and the science teacher. Participation in the learning experiment was voluntary. A letter describing the study (its aim, data management, and confidentiality and a statement that no harm would be caused to the students) was sent to the parents asking for their consent for their children to participate in the study. The participants gave their personal consent before entering the experiment. They were informed that they could quit at any time.

RESULTS

Hypothesis control

1) The average level of participants' pre-knowledge was M = 2.11 (SD = 1.28), and the average of their post-knowledge was M = 3.43 (SD = 1.47; N = 122). Pearson's product-moment test (**Figure 2**) showed r = 0.395; $p < 0.001$ (t = 4.7113, df = 120, p-value = 6.68e-06, cor = 0.3950927), allowing us to conclude that participants' pre- and post-knowledge were in positive correlation with the value that falls between a modest and strong correlation. This means that the higher the level of a participant's pre-knowledge (x-axis), the higher his/her post-knowledge (y-axis).

We see (**Figure 2**) that there were students whose pre-knowledge was "2" (11 participants), and it remained "2" which means they did not learn (as they did not change their conceptual post-knowledge level); and the post-knowledge level of some students even decreased (e.g., one's pre-knowledge level was "4", while their post-knowledge level was "2"). However, there were participants whose conceptual post-knowledge level increased clearly, e.g., considering that their pre-knowledge level was "2" their post-knowledge reached the level of "6" points, which means they learned efficiently. Cohen's kappa value 1.594 (with the Hedges' correction that was 1.599, t (119) = −9.106, $p <$ 0.001; M = −1.325; SD = 1.594) refers to quite a large effect size. H1 (*pre-knowledge level has an impact on one's SDL gain*) was confirmed.

2) Regarding participants' pre- and post-knowledge investigation by gender (**Figure 3**), we first give an overview of the gender distribution among all of the participants (**Table 1**).

This means that the gender distribution was quite equal within both age groups (in grade 8 and grade 9).

Examining the pre-knowledge average results of boys (M = 2.290) and girls (M = 2.033), the two-sample t-test did not reveal a significant difference, t (109.13) = 1.072; p > 0,05 (p-value = 0.2861). However, in post-knowledge (**Figure 3**), the two-sample t-test showed a difference: the results were significantly higher among girls (M = 3.8) than among boys (M = 3.1), t (119.77) = −2.5359; $p < 0.05$.

We also conducted a simple linear regression to explore the possible prediction of participants' post-knowledge by gender

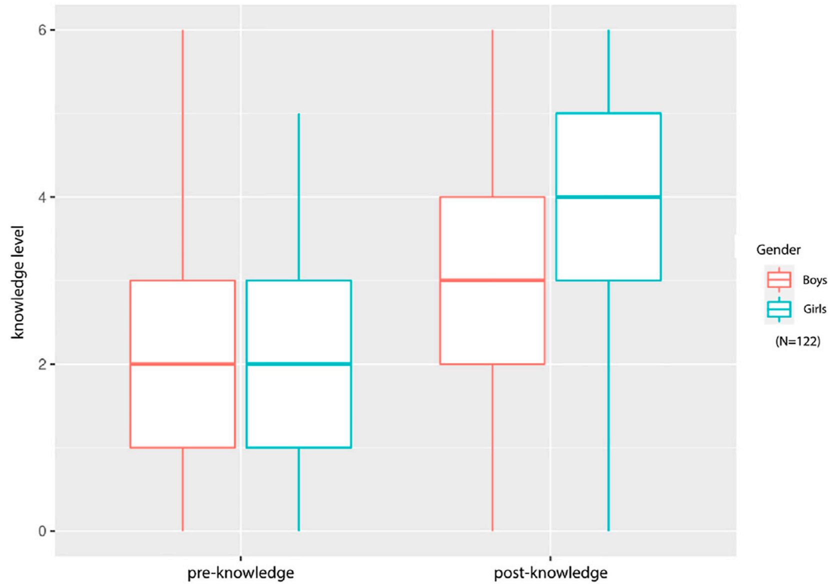

FIGURE 3 | Participants' pre- and post-knowledge average results by gender.

TABLE 1 | Gender distribution of the participants.

Gender	Grade 8 (aged 14–15 years)	Grade 9 (aged 15–16 years)	Total
Boys	52.439% (43)	47.500% (19)	62
Girls	47.561% (39)	52.500% (21)	60
Total	82	40	122

TABLE 2 | Participants' reports on their problem-solution strategies.

Problem-solution type during the present SDL task	False	True	Total	*p*-value
"We did not face any problem"	58.2% (71)	41.8% (51)	100% (122)	1.00
"We ignored the problem and continued with our activities"	82.79% (101)	17.21% (21)	100% (122)	1.00
"We asked for help from the teacher"	80.33% (98)	19.67% (24)	100% (122)	0.250
"We asked for help from the other student-groups"	91.8% (112)	8.2% (10)	100% (122)	0.050*
"We investigated on our own until we could resolve the problem"	61.48% (75)	38.52% (47)	100% (122)	0.407

and grade. The model was statistically significant (i.e., the selected feature combination significantly affects the change) with R = 0.053 (multiple R-squared). Although a weak relationship was found, the descriptive power of the model is 5% of the variance ($R^2 = 0.037$), F (119) = 3.299 (on 2) (*p*-value = 0.04034), and the gender girl, $p < 0.05$ (*p*-value = 0.0122), was the main factor (in this combination of the variables) to predict the participants' post-knowledge level. H2 (*gender predicts students' knowledge gain efficacy in SDL*) was confirmed.

3) Examining the participants' responses to the question "how did you resolve the difficulties faced during the present SDL assignment?" (taking into account the fact that they had an option to mark as many different options as they used), we see (**Table 2**) that participants most often reported that they did not have problems at all (41% of them said so), followed by the option (said by 39% of the students) that they investigated on their own until they could resolve the problems by themselves. On the other hand, 17% of the participants said that they ignored the problem and continued with their activities. Nevertheless, a proportion of participants reflected that they needed help in their SDL assignment: they asked for help from the teacher (20% of participants marked this strategy) or asked for help from the other student-groups, which indicated a statistical difference (p = 0,05) and was pointed out by 8% of participants.

Based on this outcome, we continued with a more fine-grained analysis (**Table 3**), which revealed that the problem-solution "we asked for help from the other student-groups" was more

TABLE 3 | Problem-solution "we asked for help from the other students" by grades.

Problem-solution strategy 4 ("we asked for help from the other students")	Grade 8	Grade 9	*p*-value
False	87.805% (72)	100.00% (40)	—
True	12.195% (10)	0.000% (0)	0.050*
Total	100%	100%	—

TABLE 4 | Statistics between the eighth and ninth graders' reports on the problem-solution "we asked for help from the other students."

χ^2-test	χ^2-value	Degrees of freedom	*p*-value
Pearson's Chi-squared test	Chi2 = 5.313589	d.f. = 1	0.021*
Pearson's Chi-squared test with Yates' continuity correction	Chi2 = 3.816518	d.f. = 1	0.050*

TABLE 5 | Respondings to the question "How do you usually feel about learning on your own?".

Subcategories	*N*	%
"Depending on how much information you need to remember at a time: if more, then harder; if less, then it is easier to learn on my own."	52	42.62
"It is usually not so difficult for me to learn on my own"	33	27.05
"It is sometimes difficult for me, especially with more complex tasks, because the necessary things are not remembered"	18	14.75
"It is always difficult for me to learn on my own because attention gets distracted easily when too much information needs to be remembered at once"	13	10.66
"It is often difficult for me to switch from one task to another"	6	4.92
Total	122	100

frequently marked by eighth graders (12.2%), whereas nine graders did not mark this strategy at all (0%).

Pearson's Chi-squared test on this (**Table 4**) showed a significant difference, χ^2 (1, n = 122) = 5.313, $p < 0.05$ (p = 0.02). Also, Yates' correction for continuity (that is often advised to reduce the error, especially when the actual numbers are small) indicated a difference, $p = 0.05$.

H3 (there will appear differences in participants' problem-solving strategies in the SDL outdoor assignment) was confirmed.

4) Examining the participants' retrospective feedback about their previous SDL (experienced before the current SDL assignment), the overview of the frequency of all answers is given in **Table 5**.

We see (**Table 5**) that, although it was pointed out most often as a primary difficulty, related to the large amount of information that is needed to remember at a time (43% of participants highlighted that if there is more information, then harder, if less, then easier to learn on their own), while it was said much seldom (27%) that it is usually not so difficult to learn on one's own. However, the second obstacle (15% by their own words) was related to the task complexity. The third difficulty (11%) was related to attention keeping when too much information needed to be remembered at once. In addition, also the problems related to switching from one task to another were pointed out (5%).

Detecting participants' responses to the latter question ("how do you usually feel about learning on your own?") by grades, the answers of eighth graders and ninth graders are given separately in **Table 6**.

The Pearson Chi-square test (measuring the frequency of participants' responses to the question "how do you usually feel about learning on your own?" differs by class) revealed significant differences in eighth and ninth graders' responses, χ^2 (4, n = 122) = 9.735, $p < 0.05$ (p = 0.045). This shows that different classes have given different answers. To find the effect size (using Fisher's Exact Test), the Cramer's V = 0.282 was calculated (p = 0.0230), which showed a modest relationship.

We see (**Table 6**) that the largest difference between eighth and ninth graders responses was related to the complexity of the tasks: only a few of ninth graders (2.5%) mentioned that it is difficult for them to learn on their own, especially with more complex tasks because the necessary things are not remembered, while it was significantly more often highlighted by eighth graders (21% pointed on this).

We detected each of the subcategories of the question "how do you usually feel about learning on your own?" The responses of eighth and ninth graders on each category are given in **Table 7**.

In the subcategories, we see (**Table 7**) that although 94% of the eighth graders pointed out this subcategory, 5.5% of the ninth graders said that it is difficult for them, especially with more complex tasks, because the necessary things are not remembered. This outcome confirms our previous finding (**Table 6**) that among all of the subcategories (of the question "how do you usually feel about learning on your own?"), 21% of the eighth graders (17 participants) chose the answer that "it is difficult for me, especially with more complex tasks, because the necessary things are not remembered." However, this answer was chosen by a few ninth graders (i.e., only one participant referred to this answer). The Pearson Chi-square test revealed that this difference

TABLE 6 | Respondings to the question "how do you usually feel about learning on your own?" by grades.

Subcategories	Grade 8 (%)	Grade 9 (%)
"Depending on how much information you need to remember at a time: if more, then harder; if less, then it is easier to learn on my own"	37.8	52.5
"It is usually not so difficult for me to learn on my own"	29.27	22.5
"It is always difficult for me to learn on my own because attention gets distracted easily when too much information needs to be remembered at once"	8.54	15
"It is often difficult for me to switch from one task to another"	3.66	7.5
"It is sometimes difficult for me, especially with more complex tasks, because the necessary things are not remembered"	20.73	2.5

TABLE 7 | Subcategories' distribution of the question "how do you usually feel about learning on your own?" by grades.

Reflection on one's previous SDL experience	Grade 8	Grade 9	Total	*p*-value
"It is often difficult for me to switch from one task to another"	50% (3)	50% (3)	100%	0.63466
"Depending on how much information you need to remember at a time: if more, then harder; if less, then it is easier to learn on my own"	60% (31)	40% (21)	100%	0.17837
"It is always difficult for me to learn on my own because attention gets distracted easily when too much information needs to be remembered at once"	54% (7)	46% (6)	100%	0.43914
"It is usually not so difficult for me to learn on my own"	73% (24)	27% (9)	100%	0.56667
"It is sometimes difficult for me, especially with more complex tasks, because the necessary things are not remembered"	94% (17)	5.6% (1)	100%	0.01668*
—	(82)	(40)	122	—

*$p < 0.05$

is statistically significant, χ^2 (1, n = 122) = 5.73, $p < 0.05$ (p = 0.02). Cramer's V = 0.241 (using Fisher's Exact Test) showed that this is a modest relationship.

This outcome indicates the statistical difference between eighth and ninth graders responses to the subcategory "it is difficult for me to learn on my own, especially with more complex tasks, because the necessary things are not remembered". By gender, however, there were no significant differences. H4 (*participants' self-reflections on their prior SDL experience will reveal difficulties related to complex tasks, where the contribution of executive functions is highly needed*) was confirmed.

DISCUSSION

This work concentrated on the school students' SDL skills: prior domain-knowledge (fostering conceptual conclusion), executive control (keeping focus while switching between mental operations), and strategies (inquiring, processing, relating together, and memorizing) as reciprocal prerequisites for complex learning (Schwaighofer et al., 2017).

The results showed that the higher one's pre-knowledge level was, the higher his/her post-knowledge was. This outcome is in line with prior findings: as SDL necessitates keeping in mind the sub-items, at the same time leading and controlling one's own learning, and also making relevant conclusions to be memorized in long-term memory, which all require learners' coordinated application of factual concepts and proper learning skills that together shape their pre-knowledge enabled by the executive functions to keep focus (Schwaighofer et al., 2017). This means that a higher level of pre-knowledge enables a learner to hold in mind more info-items already related together, which enhances processing in working memory, thus reducing cognitive load on executive attention; all this is difficult for those with low prior knowledge (which correlates with a much heavier cognitive load in the working memory) that hampers to keep focus and making sense of the sequential info-items to be saved in the long-term memory (Cowan, 2014; Engle, 2018), resulting in inefficient learning outcomes (Schwaighofer et al., 2017). (Our first hypothesis that pre-knowledge level has an impact on one's SDL gain was confirmed.)

In the post-knowledge, however, the girls' results were higher. This relates to previous findings on how gender can influence one's SDL efficacy: adolescent girls (compared to boys of the same age) in general have a greater willingness to put effort into learning (Schweder and Raufelder, 2019). Considering that developmental maturation of the cognitive control takes longer for boys (the impact of the testosterone on cortical advancement) compared to girls who are found to be less influenced by the cerebral structures changes in adolescence (Delevich et al., 2018; Weber et al., 2021). Female students aged 14–16 years have significantly higher SDL readiness (than the same age males), while for males, a level of SDL readiness similar to females is predicted from 21 years onwards (Reio and Davis, 2005). The same aspects also explain gender differences that have been found in learning strategies: girls monitor their own learning more efficiently, while boys, although they are keen to challenges (Liu, 2009), evince fewer control strategies than girls (Schweder and Raufelder, 2019). Therefore, a greater effort through willingness (that is more common to females as mentioned above) might have also helped girls in the present study to concentrate more effectively on only the currently needed learning items, thus enabling more efficient processing in working memory that fosters effective memorization into long-term memory (Cowan, 2014; Engle, 2018). This benefit seemingly resulted in the higher level of girls' final outcome also (in the current study) in terms of their post-knowledge. (Our second hypothesis that gender predicts students' knowledge gain efficacy in SDL was confirmed.)

The outcome regarding the question on how the problems (faced during the present SDL assignment) were resolved showed that, despite half of the participants reporting that they did not face any problem, "we asked for help from other groups" was marked by the younger age group participants, i.e., eighth graders (aged 14–15 years), while it was not used at all by the older age group students in grade nine (aged 15–16 years). This result is in line with prior work: one's learning progress is related to proper executive attention, enabling more efficient self-regulation and strategy-generation to efficiently direct oneself (Rutherford et al., 2018) as age increases (Davidson et al., 2006). It is due to the developmental maturation of the prefrontal cortex of the brain, which directly facilitates executive functions: around the age of 16 years, the frontal lobe significantly increases its white matter volume and fosters transmissions between the neuronal networks, enhancing more synchronous impulses between neurons and enabling quick, smooth, and flexible cognitive functions (Uytun, 2018). In other words, major readjustments in the brain—making it more "efficient"—take place during adolescence (Best and Miller, 2010; Blakemore, 2012). Hence, the attention of younger students can be more easily captured by irrelevant items or automatic acts when attempting to maintain the needed information (Schwaighofer et al., 2017; Engle, 2018; Rutherford et al., 2018). Nevertheless, the SDL-specific reasoning to make sense requires skills at the single (object) level and at the overall (meta) level (De Bruin and van Merriënboer, 2017), thus further increasing one's cognitive load (Janssen et al., 2010), which, in turn, can hamper attentional control (Best and Miller, 2010; Ecker et al., 2010) to keep one's focus (Engle, 2018) during multiple switching between mental tasks (Miyake and Friedman, 2012). All this severely restricts the ability to direct one's own learning (Rutherford et al., 2018). Therefore, solving complex problems is difficult, especially, for the lower (or still less mature) levels of executive capability learners (Halford et al., 2007; Nęcka and Lulewicz, 2016). The latter came out also by our results as the younger age group students needed more help than older ones. (Our third hypothesis that there will appear differences in participants' problem-solving strategies in the SDL outdoor assignment was confirmed.)

Participants' reflections on their previous SDL experience (i.e., before the current study) showed that a proportion of eighth graders highlighted that SDL is difficult for them, especially with more complex tasks because the necessary things are not remembered. In contrast, few ninth graders chose this subcategory. This outcome also relates to prior findings. As SDL requires one's metacognitive skills, in which 1) proper executive functions (enabling attentional control) enhance 2) processing effectiveness of the working memory (where the items being learned are kept in mind—to add/delete or replace info-items no longer relevant in favor of more useful or proper information), the given two aspects together function as its main components (Weber et al., 2021). However, the ability to select among alternatives, for "highlighting" some part of the information to be remembered, seems to be complicated, especially for younger students when they are required to keep track of the goal and memorize but are confronted with too much concurrent information (Kirschner et al., 2006; Butcher and Sumner, 2011). The latter is especially important in complex learning (Best and Miller, 2010) that requires constant adaptation (Dörrenbächer and Perels, 2016) to solve sub-tasks and control one's own learning, which creates a much higher cognitive load than conventional methods (De Bruin and van Merriënboer, 2017). Thus, executive control—to concentrate only on relevant info-items at a time—is crucial in SDL because it maintains an input between the learner's working memory and long-term memory, directly affecting one's cognitive operations to memorize information (Sweller et al., 1998; Unsworth et al., 2014; Nęcka and Lulewicz, 2016; Sweller et al., 2019). Executive control 1) enables us to keep in mind our plans and the needed instructions, while 2) to relate one thing to another, e.g., present/future/past and to act based on relevant information kept in mind (not only perceptual sensation), one needs 3) to inhibit impulsive, dominant, or prepotent responses to avoid answers based on the first reaction that comes to mind (Schwaighofer et al., 2017). However, in order to reach proper choices (rather than impulsive acts), premature conclusions should be avoided (Davidson et al., 2006; Miyake and Friedman, 2012). (Our fourth hypothesis that participants' self-reflections on their prior SDL experience will reveal difficulties related to remembering information in complex tasks (i.e., where the contribution of executive functions is needed) was confirmed.)

A novel contribution of this study is the data on how the participants usually felt when learning on their own within the SDL framework. This gives a rather broad overview not only of the immediate outcome of the experimental conditions but also of broader feedback on the SDL conditions, in terms of the student's perspective, in general. Taking into account the fact that as a method, autonomous learning and learning outside the classroom are indeed more and more needed, especially considering the need for remote education caused by the global pandemic situation. Based on greater attentional control to direct oneself in SDL (compared to conventional methods), this work highlights specific skills and self-monitoring abilities directly influencing students' complex learning progress. To our knowledge, this topic has so far been handled only by a few other studies (Rutherford et al., 2018). Therefore, the current work contributes to a narrow research field of SDL research among school-age learners, more specifically adolescents, by exploring their age and gender differences, whereas the majority of studies in the SDL area have been carried out in adult education contexts (Reio and Davis, 2005; Schweder and Raufelder, 2021). As a result, our work relates to the prior recommendation that all school-aged pupils can benefit from age-appropriate goal-setting and metacognitive self-management in order to improve SDL effectiveness in various learning situations (Francom, 2010; Hematian et al., 2017). Given that the goals of enhancing learners' self-directedness and fostering transformational learning are the most common aims in education, we need to assist and scaffold individual learners in developing their prerequisite skills to engage in SDL: planning, monitoring, and evaluating their own learning (Reio and Davis, 2005).

LIMITATIONS

On the negative side, although we initially involved a larger sample size in the experiment, we had to leave out a portion of the participants' data who did not follow all of the instructions assigned. The latter might be an additional example of multitasking accompanying the SDL, which in current outdoor learning activities demands participants to keep in mind many different info-items in order to complete their entire SDL assignment.

The group-work aspects possibly influencing individual learning effectiveness might have an additional impact also in our results that, beyond the present paper volume, should be studied further.

We also declare that the final number of students in grades eight and nine was not exactly the same (which to some extent can be related to the aforementioned reason). As the SDL task of the ninth graders was slightly more complex (taking into account their developmentally more advanced cognitive capability) than in grade eight, thus accompanying higher cognitive demand (of ninth graders) might have been an additional aspect in keeping in mind all the complex information (while remembering to add their identification codes to all sub-tasks). Accordingly, we do not claim that our results would show strong relations and would be generalizable in terms of the differences in participants' problem-solving strategies and in the reflections on their previous SDL experience (as the third and fourth outcome of this study). Rather, it shows the indicating value of this work and the necessity to continue further research in those variables to broaden understanding and develop suggestions in order to implement the SDL approach effectively. At the same time, our findings in terms of the pre-knowledge and the gender impact on predicting the SDL efficacy (as the first and second outcome of this study) seem to be not dependent on the age group and confirm earlier findings described in this work.

CONCLUSION

The use of SDL is a prevailing trend in schools, and developmental psychology has revealed aspects of school-age students' varying cognitive skills required for autonomous learning. In line with prior research, our work confirmed important elements pertaining to SDL that have been little discussed so far: executive attention of the learner to stay focused in processing, the heavy load demand on an individual's cognitive mechanism accompanying complex learning, and age and gender differences in those learning skills that influence knowledge acquisition especially in SDL. Based on prior research and the present results, we cannot take for granted that all students will benefit at an equal level when implementing complex SDL methods to prepare them to autonomously acquire and apply knowledge. Regarding adolescent learners' not yet fully matured cognitive skills and individual differences in this path, related to the pubertal processes of brain development, those aspects are important in preparing SDL assignments to avoid overloading the learners. The latter is especially relevant in the current global pandemic situation that increases the trend of outdoor (instead of the classroom) learning, although the learners often lack the needed skills, strategies, and abilities to keep their focus needed for the SDL approach. This can lead to ineffective knowledge acquisition, at worst also academic burnout, and/or mental health problems in students (Blakemore, 2012). Hence, it seems to be important to equip school students with proper strategies to prevent their cognitive overload, enable them to operate with resilience in their learning situations, and cope with ever-increasing information in the future—to form independent and relevant conceptual conclusions. Thus, we can maintain their motivation to foster another general aim of 21st-century education: to continue their lifelong learning based on advanced preparation and sophisticated skills of self-directed learning.

DATA AVAILABILITY STATEMENT

The data analyzed in this study are subject to the following licenses/restrictions. The data include personal data, which will only be available on request. Requests to access these datasets should be directed to onne.uus@tlu.ee.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Tallinn University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

The first author was the main contributor; the other three authors contributed equally by preparing the outdoor-learning experiment.

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Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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