

Using self-made automata to teach STEM in early childhood teacher education

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Abstract

In recent decades, an increasing number of countries have integrated science, technology, engineering, and mathematics (STEM) into their curricula for early childhood education and care (ECEC). In contrast to this trend, many ECEC professionals are still reluctant about the idea of teaching STEM to young children. A reason for this might be too little experience with and knowledge about STEM. One way to tackle this problem is to address STEM in ECEC teacher education in a way that is engaging, motivating, and practical, and shows ECEC student teachers appropriate ideas for how to teach STEM in a playful and child-centred way. This case study aims to present and analyse an innovative approach to ECEC teacher training. We let the student teachers build their own automata (toys that have mechanical moving parts) to promote a better understanding of STEM. The students were highly motivated, assessed the approach as exciting and relevant, and consequently could successfully reflect on STEM content and pedagogy.

Keywords: STEM; automata; early childhood; teacher education; motivation; experiential learning; learning development.

Introduction

Since the 1990s, the acronym 'STEM' has been used as a shorthand for 'science, technology, engineering, and mathematics' (Sanders, 2009). STEM can be seen as an integrated approach (Rosicka, 2016, p. 4) that implies interdisciplinary teaching aiming at problem-solving and encouraging students to contextualise scientific concepts within real-life situations (European Schoolnet, 2018, p. 6). Based on his research review, Chesloff advises that STEM education should start early (2013). Tippett and Milford suggest that STEM concepts are developmentally appropriate for young children (2017). Children demonstrate skills and carry out actions that promote 'STEM learning: questioning, play, processing skills, and scientific and engineering practices' (Tippett and Milford, 2017, p. 82). In recent decades, an increasing number of countries have developed strategies to enhance early STEM education (e.g. Norwegian Ministry of Education and Research, 2015).

In contrast to this trend in research and education policy, many early childhood education and care (ECEC) professionals are still reluctant to teach STEM (Parette, Quesenberry and Blum, 2010; Timur, 2012; Fenty and Anderson, 2014). One reason for this might be little experience with STEM. In a recent study by Chen, Huang, and Wu, pre-service ECEC teachers who had STEM teaching experience, were interested in STEM, or had participated in STEM-related activities, showed more STEM-related self-efficacy (2020). Park, Dimitrov, Patterson, and Park, however, found that about 70% of the pre-service ECEC teachers in their sample did not believe themselves to be ready for teaching STEM, regardless of their teaching experience (2017, p. 285).

One way to tackle this problem is to address STEM in ECEC teacher education in an engaging, motivating, and practical way that shows students appropriate ways to teach STEM in a playful and child-centred form. This case study is part of the larger project AutoSTEM (Thiel et al., 2019) that is funded by the European Erasmus+ Programme Key Action 2 'Cooperation for innovation and the exchange of good practices'. This larger project aims to develop and share an innovative approach in early STEM education and

ECEC teacher training. The innovative approach is to let young children build their own automata to promote a better understanding of STEM. In this case study, we focus on learning development in higher education (Hilsdon, 2011) by presenting an object-based teaching unit for ECEC teacher education. The research questions are:

1. How did the ECEC student teachers perceive our innovative approach?
2. How did the ECEC student teachers reflect on the content they learnt?

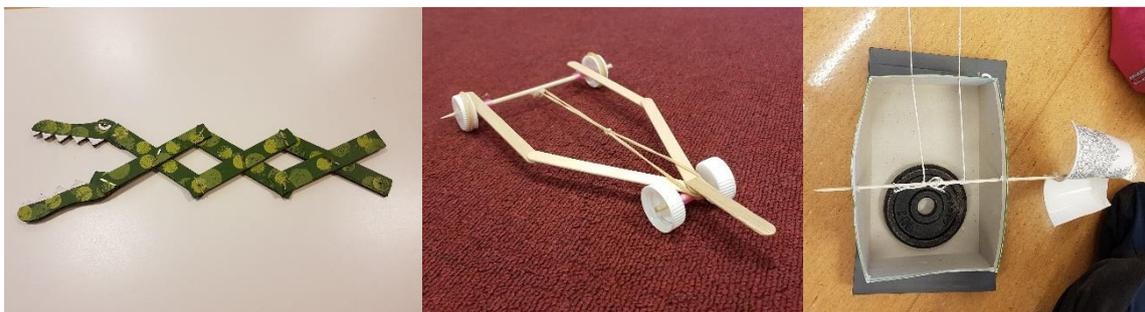
Approach and implementation

In the project AutoSTEM, we use a relational play-based pedagogy. This pedagogy is situated between the extremes of free play without adult intervention and adult-led teaching. ECEC teachers use their professional knowledge and skills to interact with the playing children to extend children's thinking and learning (Hedges and Cooper, 2018). Following Broström's dynamic learning concept, it is the ECEC teacher's task to prepare a play environment that challenges the children and encourages them to create new meanings and understandings (Broström, 2017). One way for ECEC student teachers to learn this is to experience it themselves. This corresponds with Dewey's pedagogical theory of 'having an experience' (Dewey, 1934, p. 35). This theory was further developed by Kolb (2015) into Experiential Learning Theory (ELT). ELT is used in early STEM education and ECEC teacher education (Thiel, Severina and Perry, 2020, p. 192) as well as in learning development (Kukhareva, Lawrence, Koulle and Bhimani, 2019, p. 4) because of its relationship to constructivist learning and the scientific process (Dennick, 2015, p. 53). Kolb (2015) describes a learning cycle with four steps: concrete experience – having an experience while doing something; reflective observation – reviewing what you have experienced; abstract conceptualisation – concluding and learning from the experience; and active experimentation – trying out what you have learnt, which leads to a new concrete experience.

Concrete Experience

We used automata, by which we mean toys that have mechanical moving parts. This object-based learning approach (Hardie, 2015) was undertaken with a class of 31 Norwegian ECEC student teachers in the third year of their bachelor studies. A short introduction was followed by three parallel 45 minute workshops each repeated three times. In the first workshop, with an art teacher, a group of students built a crocodile or dinosaur with a scissor-arm mechanism. In the second workshop, with a mathematics teacher, they built a car with a rubber band engine. In the third workshop, with a science teacher, they explored a self-made wind turbine attached to a winch to pull objects (see **Figure 1**). After each student had attended each workshop once, the lesson ended with a 30 minute session with the whole class.

Figure 1. The automata that we used with the ECEC teacher students: a crocodile with a scissor-arm mechanism, a rubber band car, and a wind turbine that powers a winch.



Reflective Observation and Abstract Conceptualisation

Schön (1983) distinguishes between reflection-in-action and reflection-on-action. During the workshops, we encouraged the students to reflect in action by asking questions. For example: 'what will children learn here about physics?', 'how can you support a child that has difficulties with this task?', 'how does your experience now affect your feelings about mathematics?'. In the plenary session after the workshops, students reflected on the action that they just had experienced. These are questions the students reflected on: 'what do you think about this activity?', 'is this applicable to young children?', 'what would you have done differently?', 'do you have ideas for other automata?'. The students then had to

carry out a written task in the months after the lesson: 'Choose an automaton. Describe the toy briefly, preferably with a picture. Explain what young children learn about STEM (mathematics, physics, biology, or ...) while making and/or playing with your automaton'.

Active Experimentation

Four weeks after the seminar, all students attended a five-week practical placement, each one in a different ECEC institution. Here, they had the opportunity to apply what they had learnt to children.

Method

In this paper, we analyse data from two sources. At the end of the half-day seminar, we asked the students to complete a questionnaire including ten items (see Table 1 in the Appendix) from the two subscales, 'interest/enjoyment' and 'perceived usefulness' (Deci et al., 1994), from the Intrinsic Motivation Inventory (IMI). An expected learning outcome on the syllabus is that the student develops an attitude towards STEM that includes students viewing STEM as an important tool in aesthetic learning processes and as a source of play, learning, and education (Queen Maud University College, 2019). 26 students responded on a 7-point Likert-type scale spanning from (1) 'not at all true' to (7) 'very true'. They gave their informed written consent for us to use the data.

Furthermore, we analysed the students' answers to the written task mentioned above. 18 students gave their informed written consent. We coded all utterances in the students' texts descriptively. Afterwards, we categorised the utterances according to the expected learning outcomes. The syllabus includes learning outcomes related to pedagogy (the student has extended knowledge about children's exploration, wondering, experimentation, and creative enthusiasm related to science and arts, and can foster curiosity and scaffold children's processes of wondering and creative activities (Queen Maud University College, 2019)), STEM content (the student has knowledge about STEM phenomena that one could explore together with children of any age (Queen Maud University College, 2019)), and other subjects (the student has knowledge about the use

of arts and crafts in STEM (Queen Maud University College, 2019)). We subdivided these three general categories into more specific subcategories, for example STEM was divided into the four STEM subjects, and then each subject into the STEM phenomena related to that subject. Figure 2 shows an overview of all categories and subcategories. After we categorised the utterances, we counted different things (see

Table 2 in the Appendix): (1) How many utterances belong to each category? (2) How many utterances in this category were made by every student on average, at least and at most? (3) How many students made utterances in this category?

Results

Enjoyment and perceived usefulness

The mean of the subscale 'interest/enjoyment' was 5.9 (SD = 0.6, MIN = 4.8, MAX = 6.8) with a reliability (Cronbach's alpha) of 0.84. The item with the highest score was 'this training is fun to do'. The mean of the subscale 'perceived usefulness' was 5.7 (SD = 0.8, MIN = 4.0, MAX = 7.0) with a reliability (Cronbach's alpha) of 0.89. The item with the highest score was 'I believe that this training is useful for working with STEM in kindergarten and/or primary school'. Table 1 (see Appendix) shows the mean scores for each item. The reliability of both scales is good even though the sample size is rather small. All students enjoyed the half-day seminar and perceived it as interesting and useful for their future work. Along with Deci et al. (1994, p. 132), we found that the two scales are strongly correlated ($r = 0.78$, $p < .001$).

Students' reflections

We counted a total of 355 utterances. The minimum was 12, the maximum 35, and the average 19.7 utterances per student. Every student made at least four utterances about STEM. One student made as many as 24 utterances that were related to STEM. The average was 11.4 utterances per student. This category contained 58% of all utterances. Another 36% of all utterances were about pedagogy. The remaining 6% were about other

subjects: arts and language. Not every student wrote about these subjects. 56% of the students wrote about arts and 39% wrote about language. The following example mentions arts and language in the same utterance: ‘Children learn a lot through STEM activities. They learn language, practical artistic skills, and social competence’ [Utt84].

Figure 2. Categorisation of the students' utterances in the written task.

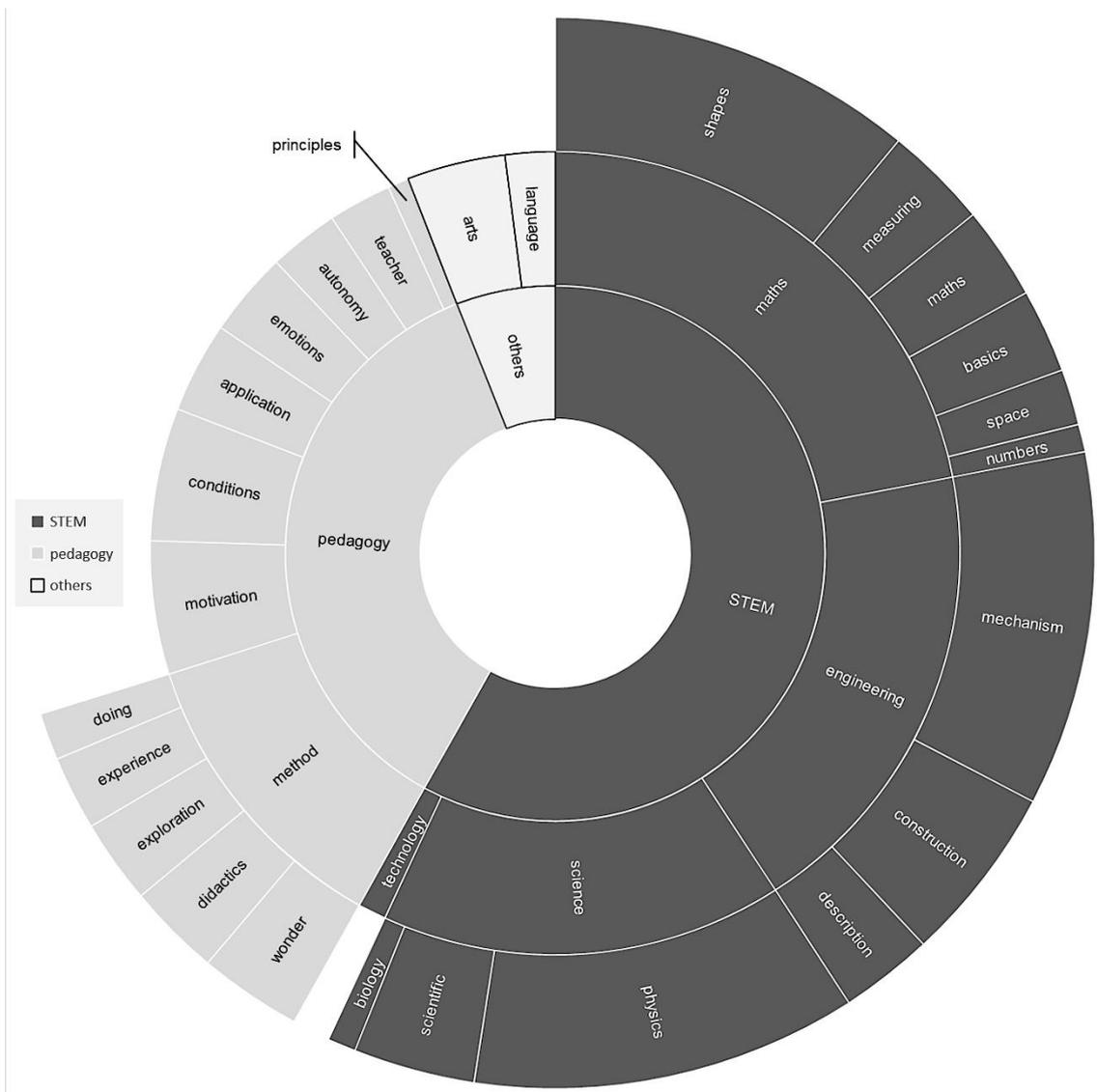


Figure 2 shows the utterances' distribution between the different categories. The detailed figures are in

Table 2 (see Appendix). Most of the STEM-related utterances were about mathematics, followed by engineering and science. We found only four utterances about technology, and

these were very general, not directly related to the automata. The utterances about engineering, on the other hand, were mostly about the automata, how the automaton works, how it is constructed, or a more general description. Within mathematics, the following topics were covered: shapes, measuring, basic methods like classification and comparing, space, and numbers. Also, ten utterances were about maths in general without referring to specific content. Most of the science was about physics, for example, force, energy, and power:

When children use this mechanical toy, they will learn about physics. Children will soon understand that if this toy shall catch something, one must apply a force. In physics, force is an influence on an object that can change the state of motion of an object. I do not think the children think about this much when they play with this toy, but I think most of them will understand that you must apply a force to make this toy work [Utt313].

All the biology statements came from three students and were related to the automaton with the scissor-arm mechanism.

13 utterances were about general scientific methods, ideas, and principles. They did not mention specific physical or biological concepts. An example of a general scientific method is testing a hypothesis:

Before the race starts, you can talk with the children about who they think will win, then the children will gain experience in experimenting. They will make a hypothesis that means they will guess who they think will win the race. The hypothesis will be tested and either confirmed or refuted [Utt330].

Most of the pedagogical utterances were about methods. The most mentioned method was that of wondering: 'We could have used the automaton when we wonder together with the children about the planet Earth and space' [Utt191].

Exploration was followed by experience and learning by doing. In the category 'didactics', we have collected other methods like teamwork, project work, and presentation. 19

utterances were about motivation. The ECEC student teachers reflected on children's interest, curiosity, and desire to learn. They wrote that the activity is meaningful and enjoyable and that a self-made toy has an intrinsic value. Another 19 utterances were about conditions. The students reflected on the preparation work, the time, and the tools that are needed as well as the children's prior knowledge and fine motor skills. Most utterances in this category, however, referred to the ECEC curriculum. Eight students reflected on applications. They described possibilities, variations, and their experiences when they made automata with children in the practical period. About half the students reflected on the children's emotions and autonomy, and the teacher's role in scaffolding children's explorations. Only three utterances from two students were about general pedagogical principles: 'According to Leontiev, an activity is meaningful when there is a match between the goal and the motive, as in play' [Utt238].

Discussion

The high scores in the two IMI subscales show that all students enjoyed the activities and perceived the seminar as useful. In early childhood teacher education, it is important that prospective ECEC teachers develop positive attitudes towards STEM. Teachers need positive attitudes to inspire the children to discover STEM phenomena in nature (Karp, 1991). This suggests that hands-on activities as proposed here help reach this goal under certain conditions. The activity should be closely related to what an ECEC teacher actually can do with children and enough time should be given to complete the activity, including reflection-in-action, and reflection on possible applications and variations.

The Norwegian National Curriculum for Early Childhood Teacher Education claims that prospective ECEC teachers shall be able to explore nature, conduct experiments, and reflect together with children (Norwegian University Counsel for Teacher Education, 2018, p. 18). The students' reflections have a strong focus on these methods. All students were aware of opportunities for teaching STEM content in a participatory and inspiring way as well as the AutoSTEM project's pedagogical possibilities and challenges. None of the students wrote about traditional teacher-led methods like explaining and demonstrating. Furthermore, the curriculum demands that the students are able to choose and use

different materials, techniques, and tools in practical work with children and make use of local natural resources (Norwegian University Counsel for Teacher Education, 2018, p. 18). Admittedly, most students chose the materials and techniques presented in the workshop, but their reflections show that they understood how to use these in practical work with children. According to one of the most important curriculum goals, students should be able to create an inclusive and varied play and learning environment for STEM exploration and to guide, lead, and critically reflect on early STEM teaching (Norwegian University Counsel for Teacher Education, 2018, p. 15). To reach this goal, the practical period (placement) was essential. One of the students expressed his experiences like this:

I used the crocodile in the practical period. The children's wonder and commitment was great. I guess it was not immediately obvious to the children how the mechanism made the crocodile close its mouth. I agree with Broström and Frøkjær (2016, p. 50) that children's wonder and questions are a good foundation for learning. What makes the automaton operate in such a way? Even for toddlers (one-year-olds) who do not have advanced verbal language skills, I see the value of exploration and wonder. Besides, I think that the automata's aesthetic expression plays an important role. I guess many children thought my 'snapping crocodile' was tough since it looked like a kind of crocodile monster that caught the children's interest more easily than a grey pair of scissors would have done. This can motivate children to play with the toy, which can then help influence the inner motivation. Broström and Frøkjær (2016, p. 46) point out that children's desire to learn is greater when they are intrinsically motivated. 'The snapping crocodile' is therefore in many ways a simple entrance ticket into the scientific world because it is based on principles that are not too complicated. At the same time, it provides many opportunities for the children to design it in creative ways. The possibilities are endless if competent and supportive teachers help and support the children in the creative process.

Limitations

This is just a small-scale case study with an opportunity sample. We did not use a pre-test post-test design, and we did not have a control group. The presented seminar was only a

small part of a larger STEM course including theoretical lectures as well as other hands-on activities. Thus, we do not claim that our findings can be generalised or that the work with automata alone contributed to students' learning. This case study aims to share our experiences with the object-based teaching approach that we have developed. It worked well with our students, but in different contexts, adaptations might be necessary.

Applications and future work

This case study showed that using automata in ECEC teacher education was perceived as interesting and useful by the students. Their reflections showed that they learnt a lot about STEM and the acquired skills that are needed to teach early STEM in an engaging way. We are now working on the development of a free online course which will be available in several European languages. The aim is to equip ECEC teachers with the tools to use automata construction for teaching basic STEM skills and concepts as well as promoting motivation for STEM.

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Appendix

Table 1. Means and standard deviation of the used items from the IMI scales interest/enjoyment and perceived usefulness.

Item		Mean (SD)
usefulness 1	I believe that this training could be of some value for me.	5.9 (.9)
interest/enjoyment 1	I feel like I am enjoying the training while I am participating.	6.3 (.7)
usefulness 2	I believe that this training is useful for working with STEM in kindergarten and/or primary school.	6.3 (.7)
interest/enjoyment 2	This training is fun to do.	6.4 (.6)
usefulness 3	I think this training is important for my professional development.	5.3 (1.0)
interest/enjoyment 3	I enjoy this training very much.	5.8 (.9)
usefulness 4	I think this is an important training.	5.5 (.9)
interest/enjoyment 4*	I think this is a very boring training.	5.4 (.7)
usefulness 5	It is possible that this training could improve my pedagogical practice.	5.4 (1.1)
interest/enjoyment 5	I think this is a very interesting training.	5.8 (.9)

Note: * This item was scaled in reverse; SD: Standard Deviation; N = 26

Table 2. Students' utterances by category.

Categories and subcategories	utterances		utterances per student			students	
	count	per cent	mean	min	max	count	per cent
All	355	100 %	19,72	12	32	18	100 %
STEM	206	58 %	11,44	4	24	18	100 %
Maths	78	22 %	4,33	0	17	14	78 %
Shapes	39	11 %	2,17	0	8	11	61 %
Measuring	11	3 %	0,61	0	2	9	50 %
Maths	10	3 %	0,56	0	1	10	56 %
Basics	9	3 %	0,50	0	5	4	22 %
Space	6	2 %	0,33	0	6	1	6 %
Numbers	3	1 %	0,17	0	1	3	17 %
Engineering	67	19 %	3,72	1	7	18	100 %
Mechanism	38	11 %	2,11	0	5	17	94 %
construction	19	5 %	1,06	0	3	14	78 %
Description	10	3 %	0,56	0	2	9	50 %
Science	57	16 %	3,17	0	9	16	89 %
Physics	41	12 %	2,28	0	5	15	83 %
Scientific	13	4 %	0,72	0	6	6	33 %
Biology	3	1 %	0,17	0	1	3	17 %
Technology	4	1 %	0,22	0	1	4	22 %
Pedagogy	128	36 %	7,11	3	18	18	100 %
Method	43	12 %	2,39	1	5	18	100 %
Wonder	11	3 %	0,61	0	1	11	61 %
Didactics	10	3 %	0,56	0	2	8	44 %
Exploration	9	3 %	0,50	0	1	9	50 %
Experience	8	2 %	0,44	0	3	5	28 %
Doing	5	1 %	0,28	0	2	3	17 %

Categories and subcategories	utterances		utterances per student			students	
	count	per cent	mean	min	max	count	per cent
Motivation	19	5 %	1,06	0	4	9	50 %
Conditions	19	5 %	1,06	0	4	12	67 %
Application	13	4 %	0,72	0	3	8	44 %
Emotions	12	3 %	0,67	0	4	9	50 %
Autonomy	10	3 %	0,56	0	2	8	44 %
Teacher	9	3 %	0,50	0	1	8	44 %
Principles	3	1 %	0,17	0	2	2	11 %
Others	21	6 %	1,17	0	4	13	72 %
Arts	14	4 %	0,78	0	3	9	50 %
Language	7	2 %	0,39	0	1	7	39 %

Note: You will find a description of the categories in the text.

Author details

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