MOTIONz; bringing experiential embodied tangible learning to secondary STEM education

The usability and suitability of educational tools for secondary STEM education and their influence on the students' learning experience from a teachers perspective

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ABSTRACT

STEM education has become more popular and important over the years, yet its integration into current education is underdeveloped. Educational tools could be the solution, especially tangibles seem to be well suited due to its experiential and embodied nature. Tangibles also offer other educational benefits, such as increased performance and engagement. However, investigations into the impact of such tools on the full learning experience of students is still sparse. In this paper, we explore the influence of experiential embodied tangibles on the complete learning experience from a teachers perspective with an experiential embodied tangible learning tool called MOTIONz. We present the design and development of the tool and the results of an exploratory study, where six educators completed a MOTIONz worksheet and evaluated the tool based on suitability and usability. Data shows insights into the evaluation of educational tools like MOTIONz and its influence on the learning experience. The results and implications offer a step towards contextualizing the full learning experience of students in integrated STEM education.

KEYWORDS

STEM education, Tangibles for Learning, Experiential Learning, Embodied Learning, Learning Experience

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1 Introduction

Science, Technology, Engineering and Math Education, better known as STEM education, is becoming increasingly more important in today's and future society [49, 73]. This type of education is able to equip our students with the necessary skills, attitudes and knowledge to thrive in life [2, 28, 29, 40]. STEM integration into current education has been a topic of interest in the design and research community [8, 62, 69, 75]. Through design especially we are able to explore and realize ways of STEM integration into current educational situations, practises and contexts. Especially tangibles could be beneficial to this integration process as its educational benefits fit the requirements of STEM very well [9, 65].

Tangibles are generally very well suited for education, as they have the ability to support the learning of complex and abstract concepts [3, 51]. Engagement can also be boosted through the use of tangibles, enabling an increase in understanding and information retention [43, 57, 58]. Another common use of tangibles in education comes with their ability to physically represent a concept or idea which allows for the exploration of the real world in a hands-on and interactive form [42, 50]. In this way tangibles are able to facilitate experiential learning. Experiential learning is often defined as "*a process through which a learner constructs knowledge, skill and value from direct experiences*" focussing more on hands-on experiences and connecting them to theory to create a deeper level of understanding [31]. This type of learning is very valuable to the integration of STEM into current education as the courses comprised of STEM are often drawing on or relating to real world phenomena to improve the learning experience [16, 71, 74]. Learning from real world phenomena is sometimes also called embodied learning, where a concept or idea is represented physically or digitally [41]. Embodied learning is connected to learning with your body, defined frequently as "*pedagogical approaches that focus on the non-mental factors involved in learning, and that signal the importance of the body and feelings*" [53]. Within the context of this study, the first definition is being used which relates to the representation of a concept or idea.

Studies on how to design tools that are able to offer experiential and embodied learning in a tangible way and their effect on education are still scarce. Some have looked into parts of the equation, focussing on discovering the benefits that tangibles offer students in current education [44] or designing new ways of tangible education for courses that are underrepresented [54].

Most studies focus on the impact of tangible tools on the students by involving them directly in their studies [22, 72]. Rarely do studies focus on the teachers perspective on the development of educational tools or even how educators view the suitability and usability of such tools in relation to their teaching practises [55].

To expand on previous research on the design of suitable and usable tools for STEM education, this paper presents an exploratory study with a mixed method evaluation approach to gain insight into the teachers perspective of experiential embodied tangibles using MOTIONz. This designs embodies a real world concept and translates it to a hands-on interactive tool which can be used in the first few grades of secondary education physics to learn about movement. Through interaction with the small scale vehicles, users can experience the concept of movement in a classroom setting and complete small exercises, in the form of worksheets, which allow them to explore and practise the topic beyond the theory.

This exploratory study was conducted to answer the research question; "*How do experiential embodied tangibles influence the learning experience of students in secondary STEM education from a teachers perspective*?". In this study, 6 educators (5 teachers and 1 technical teaching assistant) explored the full design and were tasked with completing one full worksheet. A mixed method approach was taken where both data from questionnaires and semi-structured interviews were gathered to examine, from a teachers perspective, the influence that such tools could have on the learning experience of students. The study reports on the usability and user experience of the teachers post-task and interaction with MOTIONz, including how they assess this tool to be suitable and usable in secondary STEM education physics as well as the expected influence on the learning experience of their students. And lastly, implications are presented for research into the integration of STEM education through design as well as suggestions for best practises are made for the future development of such tools.

2 Related Work

2.1 Tangibles for Learning

Tangibles have been playing an important role in the field of education and are gaining momentum in the research community [25, 43, 51, 70]. Tangibles for learning are often defined as physical objects or manipulatives that can be used to increase students' understanding of abstract or complex concepts [3]. The use of tangibles in educational settings offer a new approach to more hands-on, embodied or experiential learning amongst other things [51, 59, 61].

Research on tangibles often also refers back to Montessori education and playful learning where hands-on learning, self-directedness and collaboration are focal points [37, 52] which are too practised in tangible learning. Tangibles are often a very good medium of translating complex ideas, thoughts or concepts into something that is experienceable in a different way than just reading or hearing about it [55, 66]. They open up the possibility to extend teaching practises outside of the traditional approaches which commonly include classroom-wide instruction or making exercises from the book [78]. Studies like Ahmet et al. [80], have explored the embodied exploration of physical concepts in interactive settings, elaborating on the ability tangibles have to facilitate experiments with real-world concepts or even fantasy ones. Clifton [15] elaborates on this by mentioning that such interactive, tangible experiences could positively impact a student's understanding of abstract or complex concepts especially relevant in the context of STEM education that has a strong association with embodied phenomena.

The effect that tangibles have on students educational experiences has also been a topic of interest in the research community [5, 48, 68]. Across various educational settings, tangibles have been proven to promote more effective and engaging learning experiences [60]. A study by Price et al. [57], also shows that tangibles are able to create more immersive learning activities which results in more active engagement and an increased motivation in students. Tangibles are also well suited for collaborative and social learning as students are more likely to interact well with others which leads to better performance and learning gain [4, 64]. Studies often report on individually observed benefits of tangibles for learning [1, 77, 81], presenting insights that all contribute separately to the full learning experience. This study positions its work as an instance of looking at the bigger picture, considering the impact of experiential embodied tangibles on the full learning experience of students rather than, for instance, looking into only motivation, engagement or performance.

2.2 STEM Education

STEM education consists of four subjects; Science, Technology, Engineering and Math. Even though the name is comprised of these distinctive subjects, the definition of STEM education as a whole can differ [23, 32, 46]. STEM education has been and is a heavily researched topic, where researchers are looking into how to define it, what its benefits are, how to implement and practise it amongst other things [13]. Previous research elaborates on the impact of experiential learning, which is often typical to STEM, and its influence on the students ability to solve educational problems and gain technological skills [79]. Other benefits can be classified into three categories: cognitive, procedural and attitudinal benefits which categorizes the various ways STEM can have an impact on education [45].

Within this study, the focus is put on the implementation of STEM education in current educational practises. Several studies also focus on this implementation through the creation and testing of design(s) (probes) to a) deem its suitability to teach one of more of the four disciplines [67], b) create guidelines on how to design for the integration of STEM education [17] or c) discover the additional benefits of such design(s) (probes) [14,

19]. Next to that, studies also seem to be focused on mapping the STEM education space; looking into the current status, its teaching practises or even looking into the interest of students in the topic [24, 33].

Typical STEM education integrates problem-based, design-based or project-based learning [71]. Interventions often focus on bringing real-world context to the classroom in order to teach students skills in one or more disciplines. The type of skills students acquire in STEM education are closely related to 21st century skills, which are skills deemed needed for success in today's and future society [21, 30]. However, teachers often experience great difficulty in implementing STEM into their classroom due to several reasons. They often experience a very big increase in workload, lack of financial means to acquire material, lack of good material available or insufficient skills to implement the material in their curriculum [42].

2.3 Usability and User Experience Testing

The International Organization for Standardization (ISO) defines usability as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" [27]. ISO has created this formal definition that has become standard in the research and design community. Usability is often seen as a component of the overall user experience [20, 50]. The user experience would include usability amongst other things like emotions, attitudes and overall satisfaction of their entire experience [76]. Combining these would result in a more complete assessment of the interaction, enjoyment, effectiveness and satisfaction of a product/system [63].

For designers and design researchers, usability and user experience testing directly contributes to their success of a project. This type of testing can be used to align with user expectations as well as goals, mental models and other things that influence the user experience [36]. According to Dumas and Redish, [18] it can be done in both informal and formal ways as well as at various times throughout the design or research process. For instance, in the beginning it can be used in an iterative manner by using similar products or testing prototypes whilst in the end it can be used as an evaluative measure. Barnum [7] also makes this distinction by categorizing it into formative and summative testing where formative testing is done throughout the process, when the product/system is still in development and summative testing is done after a product/system is finished. He also identifies certain requirements for each form of testing in order to be seen as valid testing instances, as input can still be very subjective.

3 Method

An usability and user experience study was conducted to address the research question: "*How do experiential embodied tangibles influence the learning experience of students in secondary STEM education from a teachers perspective?*".

3.1 Participants

Six physics educators (five teachers and one technical teaching assistant) were recruited to take part in this study from three different secondary schools in the Netherlands. Participants from various levels of experience were included, ranging between 1-25 years of experience within STEM education. To lower problems based on familiarity and experience of teaching tools and materials, only practicing teachers were included in the study. Informed consent was obtained from all participants.

3.3 Procedure

The study consisted of six sessions with the educators, all done one-on-one. Participants were first introduced to the session and its purpose (including giving their informed consent) after which MOTIONz was introduced. A standard introduction text was used to ensure all participants received the same information beforehand.

Then followed a task that the educators had to complete. They were asked to finish the worksheet of the Red Racecar which included interaction with the prototype to take speed measurements and do some calculations with them. Participants were given an answer sheet and a calculator to complete the task. After completion, the participants were given the opportunity to further explore the other worksheets and vehicles. This lasted between 5 to 10 minutes. At the end, participants filled in the SUS and UEQ and participated in a semi-structured interview.

3.4 Data Collection

The data that was collected from the study includes the post-task questionnaires and semi-structured interview transcripts. The post-task questionnaires consisted of a System Usability Scale [11] and an User Experience Questionnaire [34].

A short semi-structured interview followed to collect more data on usability and the user experience, as well as to gain insight into the perceived learning experience of students with MOTIONz. The interviews were conducted in the presence of MOTIONz, so references to (part of) the design could be made easily by pointing or touching.

3.5 Data Analysis

3.5.1 Quantitative Data Analysis

The System Usability Scale [11] and the User Experience Questionnaire [34] were used to quantify the educators assessment of MOTIONz. Both questionnaires have pre-existing data analysis tools and approaches created by the authors which were used to analyze the data respectively. The analysis mostly included mean calculations, which were then used to create scores for usability and user experience.

3.5.2 Qualitative Data Analysis

The semi-structured interviews were transcribed immediately after each session. Inductive thematic analysis [11] was used to assess the usability and user experience of MOTIONz as well as the expected influence on the learning experience. During the analysis, a coding scheme (figure 1) was created based on preliminary reading of the transcripts and iteratively changed throughout analyzing the qualitative data. Through triangulation, the data from the coded transcripts, SUS and UEQ was combined with the goal to create a complete picture of the usability and user experience of experiential embodied tangibles and its influence on the learning experience of students.

4 Design

A short introduction to the development of MOTIONz is presented, including key features of the process that influenced the final design presented in this section.

The start of the development of MOTIONz is marked by the technology exploration done on NFCSense [38]. A technology designed by Rong-Hao Liang and Zengrong Guo presents a simple yet effective solution to incorporating a digital component into design. NFCSense is able to use NFC tags and a scanner to measure several different metrics and display them on an interface. Measuring time, speed and frequency is just one of the many things this technology can do. To find an application area of this technology, STEM education was considered and evaluated. The physics topic of movement was deemed very suitable to fit the potential of the technology and provide an application area identified by previous research to pursue further [47]. Several rounds of ideation followed to explore different design directions. This also included a series of expert interviews with teachers to establish current practises in physics education and explore what materials and tools are currently used. Five different teachers were consulted and their data used for the further development of the tool. The data gathered here helped compare research guidelines on the topic to real world scenarios, establishing a baseline for the development of this tool. Several prototypes were created and tested to figure out the best configuration of the design.

CODING SCHEME

label	explanation	examples
look-and-feel	general comments on the aesthetic of the design, both how it looks and how it feels	P2: Ziet er leuk uit, nodigt ook uit om ermee te spelen. P3: Nou wat mij opviel is dat detaillering wat ik erg mooi vind, ik ben iemand die van opmaak houd.
expectations	expectations placed on the design beforehand and comparisons made between expectation and real experience	P1: Ik had meer verwacht dat het meer experimenteel zou zijn, dat bedoel ik mee dat eigenlijk gebruik je het product alleen maar als input voor een getal
difficulties and concerns	difficulties and concerns expressed about the experience, interaction or other part of the design	P4: is er een kans dat is maar iets niet goed werkt in dit systeem of krijg je de laptop en kan je daar aan zitten?
suggestions	suggestions made to improve, enrich or extend the design or experience, incl. the added value it would bring	P6: Ja, ja van of stel je gaat onderzoeken wat de rolweerstand doet met een beweging met de snelheid van dus stel je maakt de auto twee keer zo zwaar
learning experience	any impact or influence mentioned of the product on the learning experience of the students	P4: Het is eigenlijk gewoon ook iets helemaal nieuws, heb ik ook daarop gezet. Dus Het is ook wel leuk voor ze dat ze dan echt iets helemaal iets anders krijgen dan normaal, zeg maar
suitability and usability in education	how suitable or usable the teachers deem the product for their type of education and teaching practises	P3: Ik zou het intuitief noemen, je kan het snel en makkelijk gebruiken. Maar ik zou ook denken als ik, nee ja op gebruiksgemak is hij ook gewoon goed.
embodiment	comments made specifically about the embodiment included in the design	P5: Dat het een beetje de praktijk naar binnen haalt.
experiential	comments made specifically about the experiential aspect of the design	P5: Dan kan je wat meer, in een soort projectje iets doen. P6: Leuk dat je iets kan doen zeg maar.
tangibility	comments made specifically about the tangible aspects included in the design	P2: Dat je meteen vanaf beweging en je meteen een koppeling hebt snelheid en dat ze dus een tactiele koppeling hebben tussen iets wat gebeurt en meteen daar ook een meetwaarde van zien.

Figure 1: Coding scheme thematic analysis

Throughout this process, several designers were consulted to assess its practicality, accessibility, aesthetic, user-friendliness and more to create a design fit to help answer the research question.

This process resulted in MOTIONz (figure 2), an experiential embodied tangible educational tool designed for lower secondary STEM education that facilitates experiential learning in the classroom. Figure 2 shows (partly) an overview of the MOTIONz setup, which consists of five parts: 1) track: the street-like speed track capable to measure the speed of each vehicles, 2) screen: displays the vehicle and its speed, 3) vehicles: four different vehicles to be used on the track, 4) parking space: to rest the vehicles when not in use and 5) worksheets: exercises per vehicle to apply movement theories and concepts. Each part is introduced and explained below.

Figure 2: Overview of MOTIONz, including the track, vehicles and parking space

4.1 Track

The track consists of a street-like rectangular shaped box that is able to measure the speed of the vehicles moving on it. Inside the track, an NFC scanner and Arduino Uno can be found that are able to collect speed measurements and send it to the computer to be displayed visually. The track was created to look like a real street to create a feeling of familiarity and representation of the 'real world'.

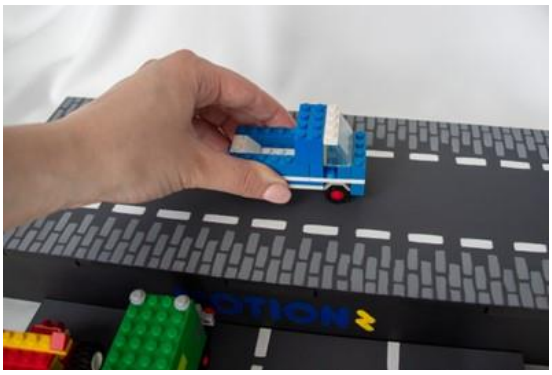

Figure 3: MOTIONz speed track

4.2 Screen

A screen, or laptop display, is needed to display the data collected by the NFC Scanner. A basic interface (figure 4) was designed to display the vehicles name and its speed. Because the average speed measured by the NFC Scanner is between 0-20 km/h, two different values of speed are displayed on the screen. On the bottom, the real speed that is measured can be seen and above that, the estimated speed. This distinction was made because real vehicles do not have an average speed of 0-20 km/h and modifying the speed without explanation would also seem unrealistic. The real speed per vehicle is used to modify it after which both values are displayed, the estimated speed (a multiplication of the real speed) is similar to that of the vehicle in the 'real world'.

Figure 4: Digital Interface of MOTIONz, displayed on a computer screen (including the name of the vehicle, the estimated speed and the measured speed)

4.3 Vehicles

Four different vehicles were created from LEGO [35] to represent a variety of 'real world' vehicles. Figure 5 shows all four; the Red Race Car, the Blue Truck, the Green Freight Truck and the Yellow Postal Van. Each vehicle is tagged with two NFC-tags (figure 6) that the NFCSense Library [39] used to identify the vehicle and measure the speed whilst it is being moved on the track. These NFC tags are also used to identify which multiplication factor is used during the speed calculations.

Figure 5: The 4 LEGO vehicles included in MOTIONz

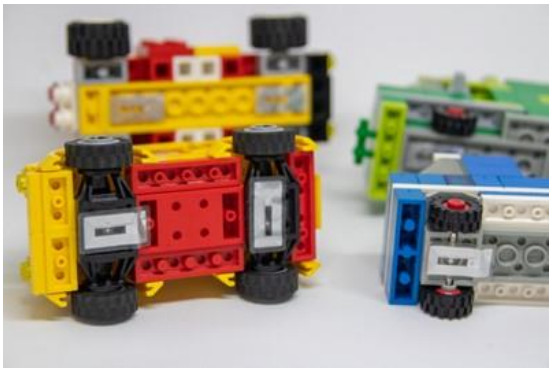

Figure 6: Example of NFC tag placement on the vehicles

4.4 Parking Space

A parking space (figure 7) was designed to store the vehicles whilst they are not in use. It merely serves as a storing facility and has no other purpose. The intent behind it was to create a more realistic representation of the 'real world' as we too leave our vehicles in designated parking spaces and not randomly in our environments.

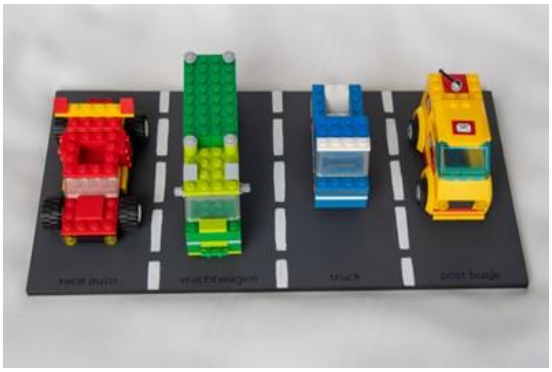

Figure 7: Vehicles in the parking spaces

4.5 Worksheets

Each vehicle is linked to their own worksheets (figure 7). Worksheets are designed to link MOTIONz experiential learning to the theory and concepts of the physics topic movement. These sheets were created based on reference material sent from several educators in the early stages of this study. This current material was then translated into exercises per vehicle which resulted in the creation of the worksheets. Each worksheet aims to let people interact with MOTIONz and use the measurements to solve exercises. Stories around each vehicles are created to make it a better representation of the 'real world' where Devon drives the Race Car on the Zandvoort Circuit and Malou drives around in her Postal Van to deliver packages.

Figure 8: MOTIONz worksheets

5 Results

The results from triangulating the data can be divided into two sub-categories; 1) the usability and user experience of MOTIONz and 2) the perceived influence on the student's learning experience.

5.1 Usability and User Experience

The System Usability Scale (SUS) [11] results produced a score between 0-100 per participant which correlates to the percentile ranking. This score is then able to inform about the overall usability rating of a product or service, often together with task completion time and task accuracy [36]. Figure 8 shows the overall SUS scores of each participant and the mean score of the whole data set. Evaluative studies [6, 56] have shown that a score of 68 is considered to be average and above 68 would then be considered above average, with an 80.3 or higher ranking to be in the 10% of top scores. If these scores are combined with the task completion time and task accuracy (figure 9), it may be suggested that educators assess MOTIONz to be very usable for its intended use.

p1	77,5
p2	87,5
p3	87,5
p4	80
p5	82,5
p6	75

Figure 9: Overall SUS scores from participants

Average SUS score	81,7	percentile
Average completion time	371,5	seconds
Average correctness	100	%

Figure 10: SUS scores, task completion time and task correctness

The User Experience Questionnaire (UEQ) results provides even more details about the assessed product due to it being a more extensive list of items to be ranked [34]. This questionnaire was used to elaborate further on the SUS and give more insight into the experience of the educator from an emotional standpoint. Results of the UEQ are categorized into six items which inform about specific parts of the design which was assessed. Figure 10 shows the mean and variance of each category which can be interpreted as follows. Each score is calculated to be a value between -3 (very bad) and 3 (very good). Scores between -0.8 and 0.8 are considered to be neutral evaluations, scores above 0.8 are positive evaluations and scores below -0.8 are negative evaluations. Five out of the six items (e.g. **attractiveness, perspicuity, efficiency, stimulation and novelty**) are above 0.8, suggesting there is a positive evaluation of MOTIONz on those criteria. The fifth one, **dependability**, is 0.75 showing there is a neutral evaluation of this criteria but as it is so close to 0.8 it might be considered to be on the positive side rather than the negative side of evaluation.

Attractiveness	1,611
Perspicuity	1,542
Efficiency	1,667
Dependability	0,750
Stimulation	1,125
Novelty	1,333

Figure 11: UEQ Scales; means per category

Both questionnaires provide a quantifiable score on the usability and user experience whilst the qualitative data from the semi-structured interviews allowed for more detail.

Participants could easily see this tool being used in their **current teaching practises** next to what they are already using. P1: "*So I can imagine that if we were to use it then we would first use the time-ticker and after that this device*" and P4: "*The theory comes really close to what we already use, in terms of the worksheets, and that is really nice because then you can immediately start using it*". Other comments were also made about its suitability in comparison to the type of student or class they would have, P5: "*I think that if you were to do this with a Gymnasium class, that they would very enthusiastic, would love it and immediately start working with it. But with another class, who might prefer other methods, it would not perform as well*" and P3: "*It depends if you are a thinker or a do-er. In my opinion it depends on the moment, everything works in education but nothing works all the time*". At this moment, concerns about it being suitable for all the different contexts and situations within education appeared but as mentioned by P5, "*But I do not know if that would be any different in other experiments, there you would have this too so I do not think the risk would be higher here or anything*" it illustrates very well that the educators think it all depends on the moment but would overall see great use in the tool.

Thoughts about the **accessibility** were also expressed by all participants at different times. P6 called it "*well yeah, very intuitive for sure"* and *"I immediately know what I am supposed to be doing*" highlighting how easy it would be for students to use it, even without a teachers explaining it. P4 also confirmed this by saying "*I would even say, for a class that you think would*

be able to handle it well, skip the whole explanation and just let them try out the device and the vehicles and good luck". P2 also relates the level of accessibility to the previous experiences of students from when they were younger, mentioning "*from the moment you would see this, especially children who have played with cars before, they would immediately want to play with it, move it. But you would also have students that would not even read and just start playing, who will get immediate feedback on how it all works*". But the overall consensus of all participants seemed to be, as summarized by P3, "*I would call it very intuitive, you can use it quickly and easily*".

When asked about the **suitability** of such tools in education. Participants mentioned the enrichment of current materials that MOTIONz could offer, P1 just stating "*I think it is a good addition*" and P2 saying "*it can be both a good addition and a replacement. It depends on the group of students. But definitely an addition in terms of motivation*". P4 also linked it back to the three learning needs of autonomy, competency and relation saying "*It can be a good addition and I think it can really help, especially in terms of autonomy*" and *"I do not think it can make them really more competent but offer them the possibility to practise things more easily which might give them the feeling of being more competent*". P5 also mentioned the tangibility and experiential learning of MOTIONz and compared that to the suitability of such tools by saying "*I think it can be a really good addition and that comes back to what I said, which is the practical aspect, that they can really do things*". When asked about the suitability, P6 also highlighted the different options you would have to implement this in class; "*I think it can be a really good addition. I think you could do both, a lesson of 60 minutes is very long so you can do it as an introductory thing but also the last 15 minutes they can do it*". They also mentioned the amount of time teachers have to prepare and sometimes they have to choose efficiency "*I think it is a great addition for a piece of classical instruction or when you need a small practicum*". P4 also linking back to this by saying "*it is ready to go and I really like that*" and "*I think it is really do-able to finish a worksheet in a lesson instead of a practicum that takes very long to set up, execute and clean up*".

5.2 Learning Experience

The educators also had a lot to say about the potential influence on the **learning experience** of students. P2 saying "*You know I can put four boxes with wheels here and then the students are like 'oh well cool' but this would entice them more and maybe even spark more motivation*" and P3 mentioning "*the haptic perception of length, so determining something by touching. You can learn something by moving and I think that makes it better*" when referring to the impact it could have on students learning purely from it facilitating tangible interaction. P4 also linked it back to playful learning, saying "*it is playful learning which challenges them also a bit. There are playful elements that I think make students more unaware of the fact that they are actually learning so much. That is in my opinion something we should try to have more of*".

The **tangible and playful aspects** of MOTIONz seemed to be resonating with the participants quite often with P4 saying "*the playful learning, really trying something out and doing*" when asked about the educative value. P6 also mentioned "*you are allowed to really do something, so learning with your whole body. That is still something that I want to incorporate even more and which makes stuff stick better with students as well*" relating tangibility to better memory and recall. P3 also highlighted the change of pace that tangibility offers compared to the more traditional ways of teaching physics, saying "*I think it is just really nice to just do things like this for a change*". P5 related the tangibility and playfulness to the accessibility by mentioning "*it is not difficult, making it very accessible. And then they actually have to do something where something really happens which can help them, I do not know specifically how but I see lots of opportunities*".

The **embodiment** of the design seemed to be related to a better learning experience for students as well. P5 saying "*it can bring a bit of reality into the classroom*" which P4 also highlighted by saying "*you are giving them a piece of reality, which I think is awesome*" and "*that translation to reality makes it even better, I did not expect that and that makes it very cool*". P6 also mentioned "*it fits better with the student's perception of the world*" arguing that the link to reality is indeed better "*and more fun*" which was supported by P3, who said when asked about the educative value "*the translation and link to the real world as well as the link to previous knowledge*" whilst also mentioning later on that "*education tries to balance reality so the circuit in Zandvoort or the Frankfurt-Eindhoven route does that*" referring to the content of the different worksheets.

The influence on **motivation** seemed to be mentioned quite often by participants as well, P2 even calling it "*a bit more inviting*" and "*it will definitely be better, specifically due to the motivation and that will for sure have a good impact on the learning experience*". P1 confirming that by saying "*I think the improvement is really in the motivation. They are seeing something new and fun but still have to work on a physics exercise in the end*". The motivation was also connected by P4 to the playfulness of it by mentioning "*it is better, not because the theory is taught better but because they are doing it in a playful way which makes them much more invested and motivated".*

6 Discussion

The research question aimed to contextualize experiential embodied tangibles for learning and its influence on the full learning experience from a teachers perspective. This section discusses the interpretation of the results, limitations, and future research directions.

6.1 Interpretation of Results

The results from the exploratory study show a good usability and user experience score for MOTIONz current design. Teachers related their scores mostly to the design characteristics; experiential, embodiment and tangibility. They envisioned these three things to have a great impact on not just the learning experience but also the suitability and usability of tools in current secondary STEM education which supports and extends on previous research findings [51, 59, 61]. Teachers deem MOTIONz to be fitting to their teaching practises as it embodies what they want to do and teach in class. The design would provide a nice alternative from current tools and material as it is deemed usable in different classes and setups. However, there were some remarks about it being too simple. MOTIONz only measures one thing; speed, and according to teachers this would not be enough to acquire such a tool. Several mentioned they were definitely willing to use it but wondered about the costs it would bring, a concern that is commonly expressed on educational tools [42]. The tool is currently designed for the first few grades of HAVO/VWO but teachers see great promise for extending the tool beyond that. Adding more features, like figure creation or acceleration, would make them want to use it more often. On top of this, it would address the cost concern; more options would make it a better investment for the school as it would be able to cover more physics topics.

Considering the learning experience, the teachers expect there to be a similar or increased experience when using such a tool as MOTIONz. They associate this again to the three characteristics mentioned before (e.g. experiential, embodied, tangible learning) which in their opinion, come with a lot of added benefits and value. First, they link an increased learning experience to motivation due to the fun factor the design embodies. In their opinion, the fact that learning is made more fun will increase the students' overall motivation which is in line with previous research. Studies have shown that when learning activities are more enjoyable, students are more likely to be motivated which would result in more active participation and investment in their learning process [43, 57, 58, 77] which the teachers are striving for in their classes. The results of this study support this whilst also providing insight into which design characteristics increased enjoyment might be rooted in.

Secondly, teachers also expect there to be a more positive learning experience as MOTIONz facilitates learning by doing, also known as experiential learning. Experiential learning has been proven to beneficial to academic performance [31] which is supported by the results found in this study. Teachers expect there to be an increase in memory and recall of physics theory as they see that an activity where students are actually doing things with the theory they learned, makes them better at remembering what they have learned in future lessons which supports findings from previous studies [10]. Nonetheless, they do not think MOTIONz to be superior to current teaching tools and materials but rather an extension thereof. Teachers believe the tool not to be better at teaching the theory but better at the practising it, highlighting again the experiential aspect of MOTIONz which they believe to contribute directly to an increased learning experience and potential academic performance which is in line with previous research.

Teachers are also linking learning by doing to motivation and fun, mentioning that the learning by doing is often more motivating for students than just making regular exercises in a book. Previous research often focusses on establishing specific benefits to tangible, experiential and/or embodied learning instead of focussing on the bigger picture [44]. However, this study is able to link different design characteristics and their impact on education together, making us better able to see and asses the influence of such tools on the full learning experience. This study is also able to provide an expert view on educational tools, whereas previous work often focussed on the students point of view [22, 72]. The results from this study confirms and builds upon previous work by providing a more contextualized view on educational tools and their suitability and usability in current education. Though there were several suggestions made to extend the design beyond its current boundaries to make it more widely usable, teachers think MOTIONz would be highly usable and suitable for the context it is currently designed for. They say it is ready to use, its simple and accessible design makes it ready for the classroom and with the worksheets, students are immediately ready to practise their newly learned movement theories in an experiential, embodied and tangible way.

6.2 Limitations

This study aimed to gain insights into the teachers perspective on the influence of experiential, embodied and tangible educational tools on the students learning experience. Even though the results presented here appear to be promising, they can be seen rather as preliminary findings. A small sample size (6 participants) might have given more similar data than expected. The data showed lots of overlap in opinions on the usability and user experience of MOTIONz, often highlighting the same features or benefits of the design. A bigger variety of perspectives could have created more reliable results, possibly by consulting more and more diverse educators; including a bigger range of experience levels, pedagogical practises or including educators from more schools. Even though the sample size for this exploratory study might be suitable, extending beyond it might create more diverse and reliable results. Next to this, the data shows slight inaccuracies in the UEQ. The data pattern analysis showed some discrepancies, calling the input from one participant critical and highlighting two others that could be suspicious. A bigger sample size could allude to a solution for this, but further research needs to be done in order to assess its cause and solve it. The semi-structured interviews done after the SUS and UEQ helped create more insight and depth into the

usability and suitability of MOTIONz. However, participants often focussed more on the limitations of the current design rather than its possibilities. The questions might have been formulated in such a way that participants interpreted it differently than intended. More development is needed to assess the suitability of questions and rewrites are needed to make sure more focus is put on the current usability, user experience and learning experience.

6.3 Future Work

Several suggestions for future research are made based on the results and process of this study. Future design development could focus on extending the topic coverage. More options could be added, like measuring acceleration/deceleration or letting it create graphs automatically. Adding features like this would make the tool more widely applicable due to its ability to cover more topics in different grades and levels.

Next to this, MOTIONz also need to be tested with students in class. This would allow for the data collection of different stakeholders within education and provide a more extensive view on the usability, suitability and learning experience. Students are able to give a different perspective then their teachers and might address different features of the design than they would. Comparing the results of these studies might allow future research to be able to create a more accurate overview of the impact on the learning experience than now.

Lastly, more approaches could be explored to involve educators more actively in the design process of educational tools. Results show they often have great suggestions on how to solve certain challenges or make it even more well-suited for its intended goal than just designers or researchers are able to do. Involving them in co-creation or co-design sessions would allow for a more collaborative approach to designing for education. This could potentially make it easier to design educational tools but also make the tools better as you would be actively involving experts into the design process.

7 Conclusion

This paper presented an exploratory study on the influence experiential embodied tangibles could have on the learning experience of students in secondary STEM education from a teachers perspective through a design embodying the aforementioned aspects called MOTIONz. MOTIONz was used to understand the suitability and usability in current education and contextualize the full learning experience in relation to such tools. Through triangulating the mixed method data, we report on the benefits tools like MOTIONz could have, the potential effect on the learning experience of students, the usability and suitability of experiential, embodied tangible learning tools, and the current usability and user experience according to teachers. The study aims to contribute knowledge about the teachers perspective on educational tools and how they perceive the context of such tools including its influence on students. MOTIONz is ready to be used in the classroom, but further development could strengthen its positioning as educational tool and material. Teachers think MOTIONz to have several of the key factors they are looking for in educational tools. They see the potential it has to positively influence a student's learning experience by linking it to increased motivation, learning by doing and bringing a piece of reality into the classroom.

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Appendix

Appendix A – Design Research Process

A visual was created to show the full design research process used in this project. Next to this visual, a short description on the most important or biggest activities can be found in this chapter as well. Both parts can be found below.

Elaborations Biggest Activities

Literature Research

To kick off the process, extensive literature research was done to identify areas of opportunity and discover potential directions for the project. I focused my efforts on establishing a research foundation that I could use to build upon in further stages, the goal was to create a broad overview of what was out there and to see what sparked interest for me to pursue. A deep dive into the following topics/areas was done:

- STEM education, in general
    - STEM in secondary education
- Tangible User Interfaces (TUI)
- Graphical User Interfaces (GUI)
- Technology in the Classroom (mostly case studies)
- Internet of Toys (toys that are connected)
- Constructivism
- Computational Thinking and Empowerment
- Gamification
    - Specifically in the context of education and playful learning
- Educational Tools
    - Specifically case studies of them

The result of this activity was a very broad but solid foundation of different direction which were then further used in brainstorming activities. It not only helped inform the brainstorm of potential design probes but also helped establish several interesting research directions to explore further.

Research Question, Direction & Framing

This activity was done throughout the whole process and definitely proved to be a bit of a challenge for me. The first few framings I created for my own research felt uninteresting, unoriginal or not novel enough. Several iterations on a question with direction were done to establish some options. Mostly literature research and design ideations helped determine what my final framing became. From these continuous activities I have learned to sometimes just make a choice and try it out, to avoid getting stuck in my own head too much. I see now that having that solid research foundation to build upon really helped, which is why I continued to evolve that foundation throughout the whole process to make sure it was up-to-date as well as still relevant to what I was doing. It helped with the final framing massively as I was continuously researching what others were doing that was similar to my own process, this helped me determine how to exactly frame my work and how to make that make sense in the research environment that was already out there.

Expert Interviews

During my search for research framing, I found a need to use my user-centered skills and get inspiration from something other than papers. I decided to use the opportunity and set up several expert interviews with physics teachers to help me make sense of the context my project would be in. I reached out to some people in my network and held 5 interviews with teachers. The goal of these short interviews were to establish current practices in secondary STEM education, understand current experiences and figure out what their wants and needs are in educational innovations. Doing these sessions helped me mostly on a personal level as it allowed me to reach back into my repertoire and feel more at ease in the process I was in. The insights also helped with initial prototyping and trying out different ideas. The teachers confirmed the direction that my project was being taken in and helped me see the relevance in the real world, and not just the research world.

Benchmarking

Benchmarking was done soon after the interviews to establish a foundation of already existing designs and design probes that were similar to what I wanted to create. The goal was to have an overview and being able to draw on certain aspect of the design during the prototyping phase. I have researched several commercial and design case studies to determine a benchmark. I looked at their strengths, weaknesses and design specifications and summarized my insights to be easy to refer to later on. It helped gain insight into the market- and design landscape of STEM educational tool, which also confirmed the lack thereof at times. The activity helped me feel more confident in my work and research direction, it showed great potential in the area I was pursuing and made me feel I could add some real value with my work upon being finished.

The design requirements and specifics extracted during my benchmark helped form the first ideation phase in my process and allowed me to continuously reflect on these items in order to create something that builds upon existing work and use that knowledge that was created.

Prototyping

Several ideation phases were done throughout the process, which included a few rounds of prototyping as well. The next chapter (Appendix B) also elaborates on these in more detail. Doing continuous prototyping simultaneous to my research framing, helped strengthen the other. So being able to create physical designs and be a designer inspired the framing and vice versa. I was able to work out my ideas in the physical sense, which helped my process massively. I am someone that thinks mostly in a visual space and have a problem of being too stuck in my head. These activities helped get out of that which ended up benefiting the framing even more than I initially expected.

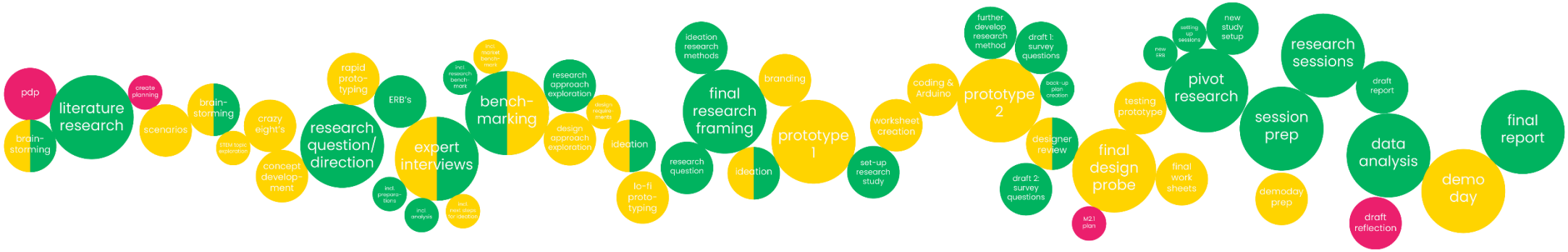
Several feedback sessions were also held to further improve my prototype. Sessions with my expert, Rong-Hao Liang, helped me further the technology side of the design the most. But he also provided me with some great critique points to make me think about more than just that. A designer review helped with identifying some user experience pain points and just general feedback on how to improve the aesthetic of MOTIONz. Consulting others helped me improve things like aesthetics but also usability and suitability.

Pivoting Research

Unfortunately I had to pivot my research as I was not able to work with students anymore. The school I was in contact with decided that there was not enough time to do this which resulted in me having to change my framing from students to teachers (as I would be able to work with them). I felt pretty discouraged for a minute but then decided to take this change and make the best of it. My original framing included the influence on the cognitive or learning abilities of students in secondary education, which was not relevant anymore. In my opinion experts (teachers) could only tell so much about that, so a change was needed that would better suit the participants I was going to be working with and the ability they would have to assist me in my work.

I reframed everything to focused on the full learning experience of students. Teachers are the perfect people to explain things from a top-down view as they are the experts in the field and they see the things I want to report about happening in front of their eyes. They are able to give a birds view to the full learning experience which made me able to create a framing around the context and the potential influence of such tools like MOTIONz on the bigger picture, and not just individual aspects (like performance, engagement, collaboration, etc.). Eventually I found my footing and with full steam ahead setup all of my sessions. I dived into usability and user experience testing which was deemed very suitable for discovering the real suitability and usability of STEM educational tools. Together with a semi-structured interview, I could gather lots and lots of data to be able to give insight into the bigger picture around educational tools and their impact on current education. I am very happy what I achieved, even though it was very tough to get there. Lots of brainstorming and consulting some other people helped me find my framing, which ended up all working out for me.

DESIGN & RESEARCH PROCESS



design activity

research activity

other

CONTINOUS ACTIVITIES

e.g. activities that were done throughout the process and were not always limited to an individual activity or other specfic time

(sometimes they were big activities, at those moments they are mentioned in the visual)

research framing
(reading & analyzing papers and working on research question)

feedback sessions
(having several in-depth sessions for receiving feedback and using this as a tool to help guide my process)

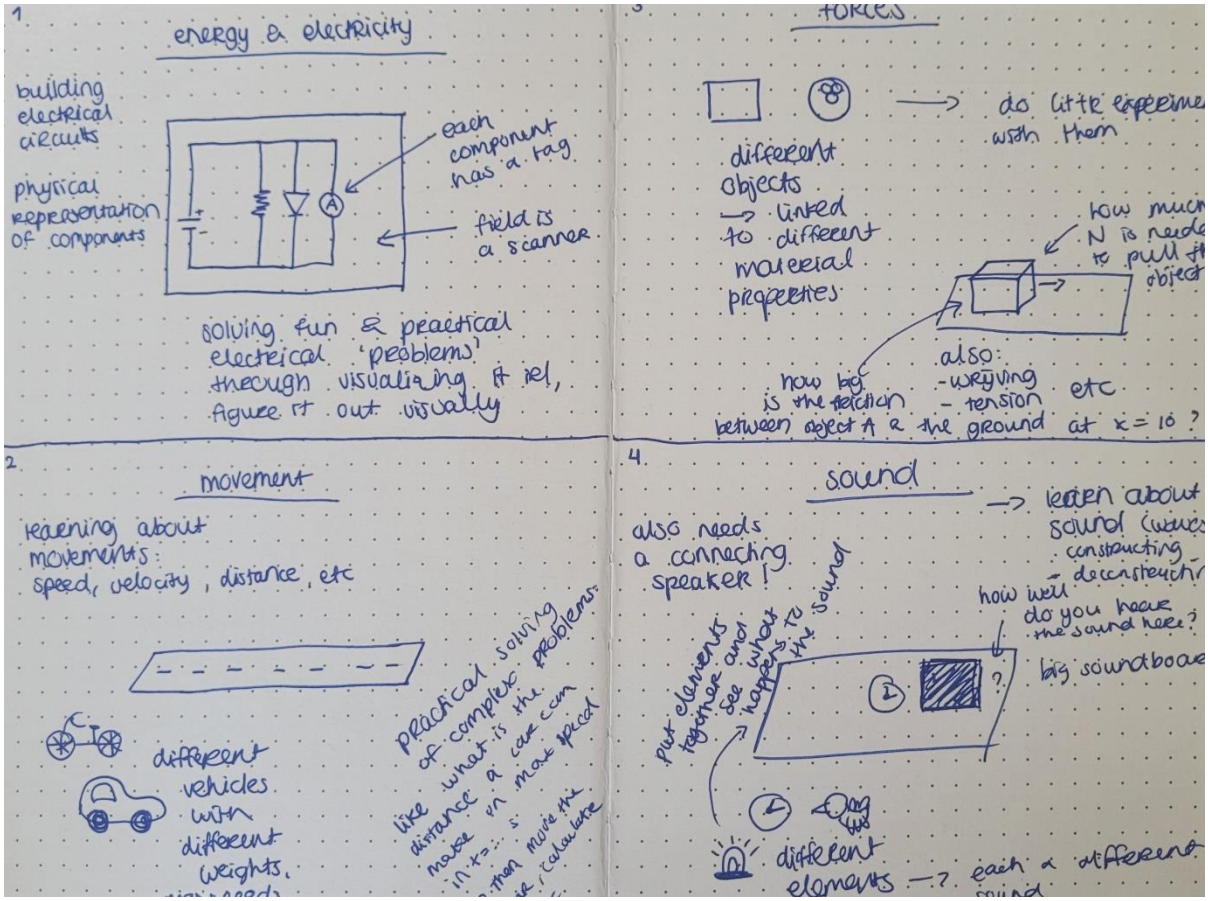
report writing
(working and creating draft versions of report pieces and the final report)

Appendix B – Development of Probes

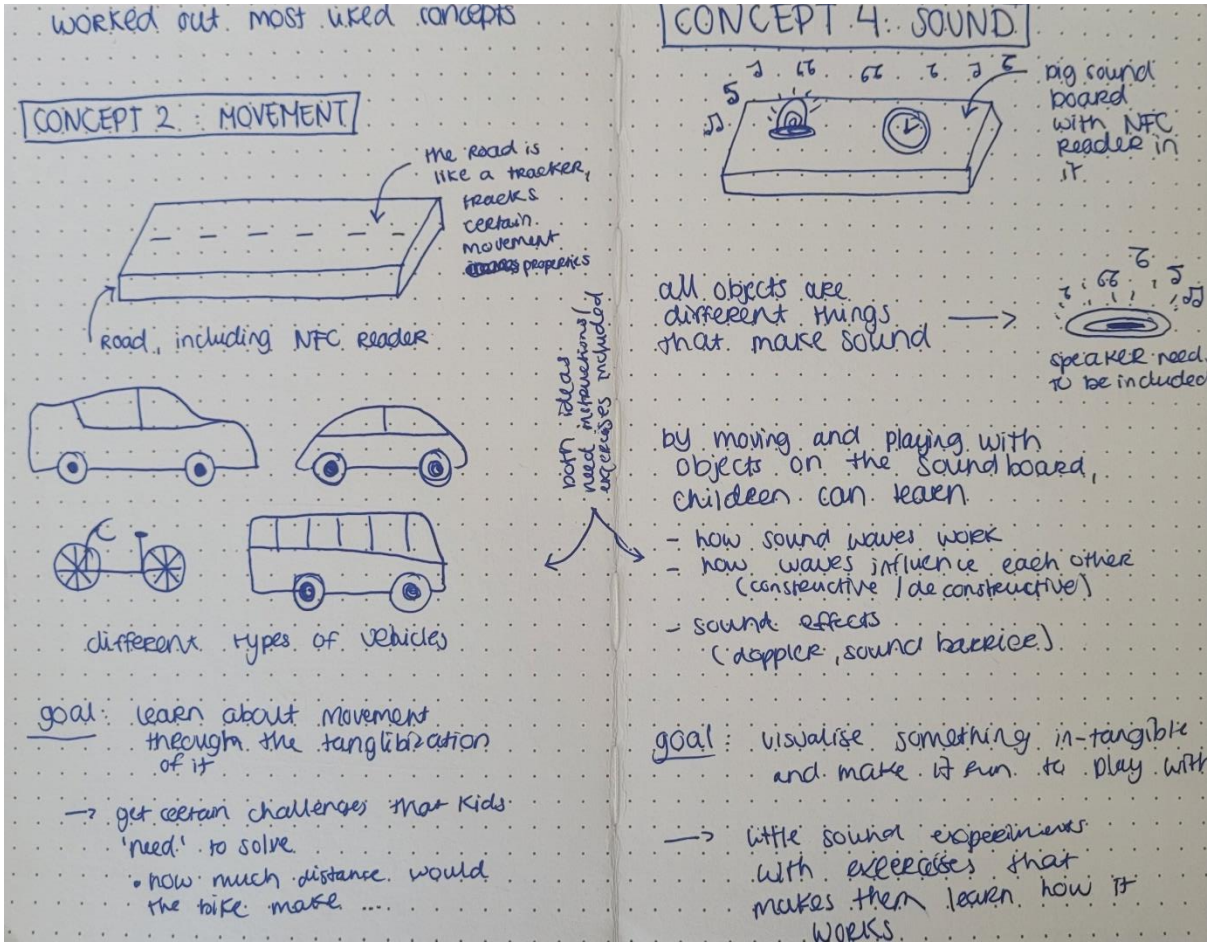
Throughout the full design research process, several iterations were completed which resulted in the creation of different prototypes and design probes. This chapter elaborates on the ideas, concepts and prototypes created during this project and comment in more detail on the development of them.

Initial Concepts

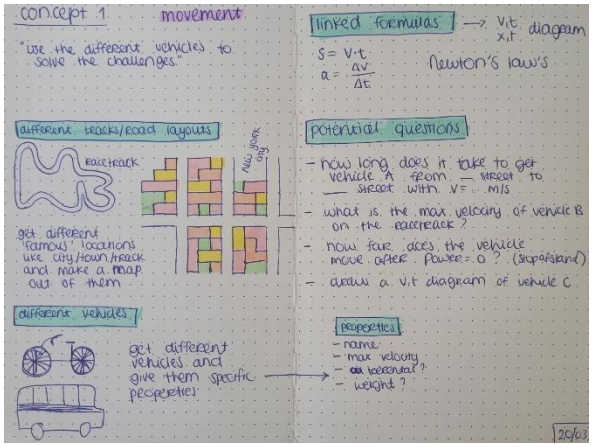
The first step of the development of probes includes the creation of the initial concepts. Below you can find the first four ideas which were created based on STEM education topics in secondary school.

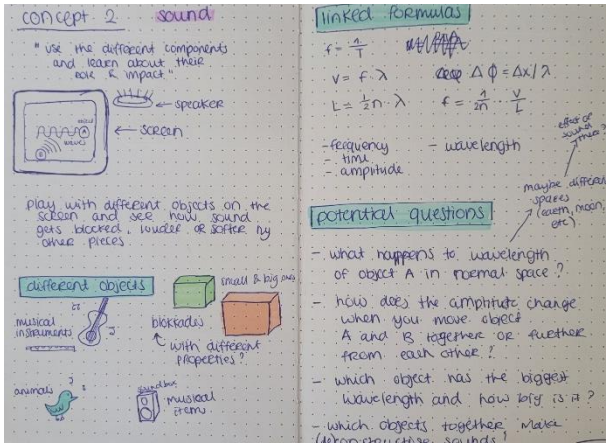


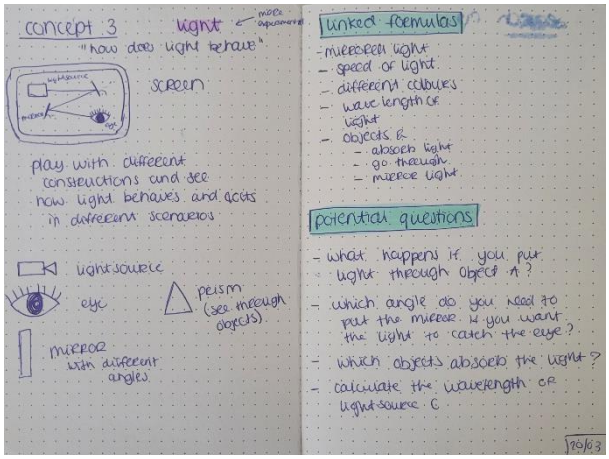
These four concepts where then refined through feedback and further ideation.



After this round of concept development. New concepts were created and old ones even further elaborated upon. This resulted in the three concepts below which were then used during the expert interviews to test the waters in terms of subjects.



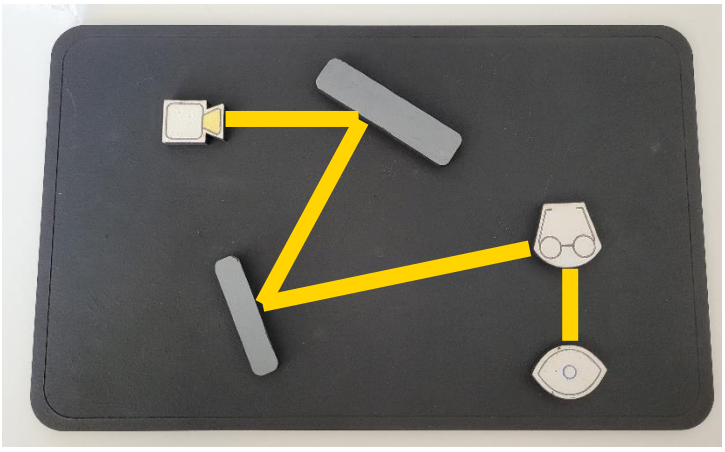


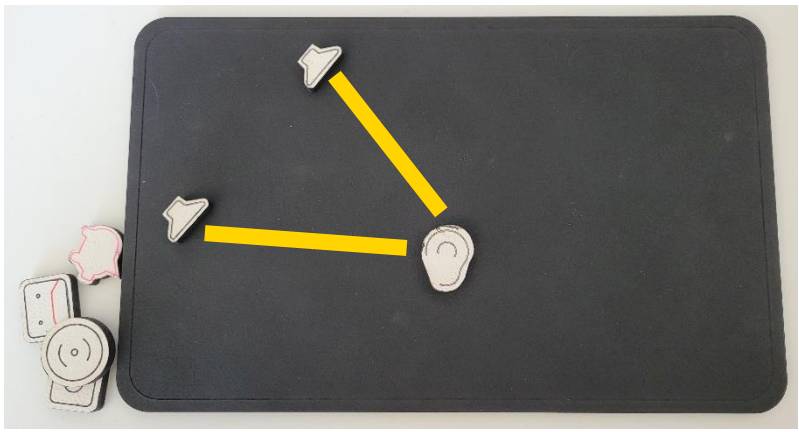


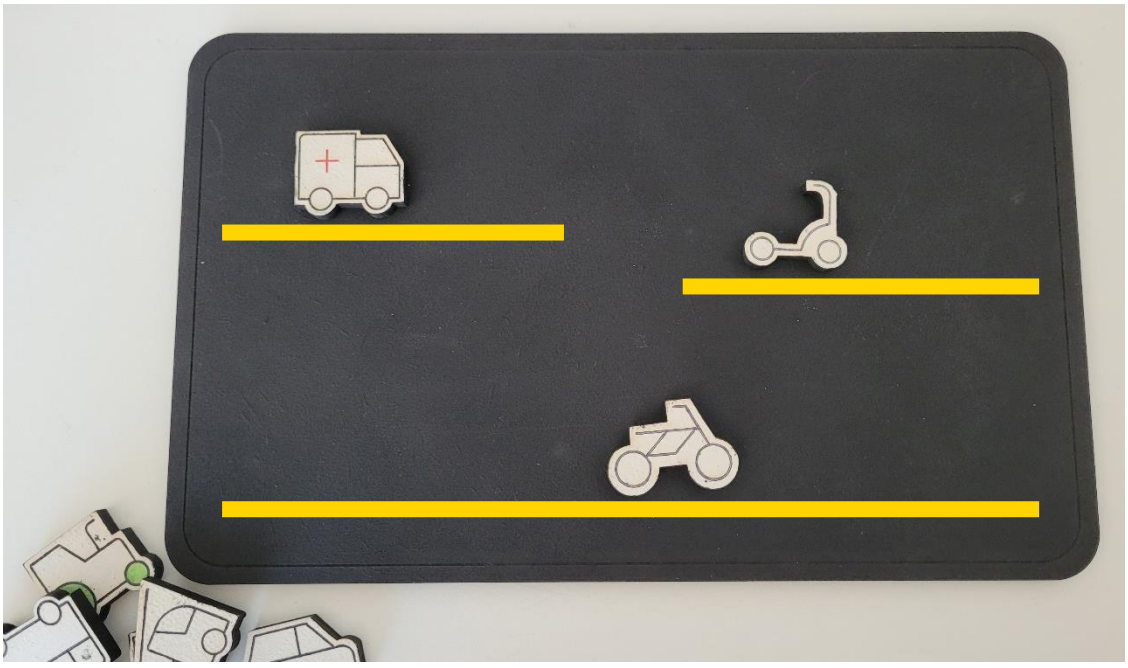
First Prototypes

After concept development, a paper prototype was created of the movement and sound concepts.

These were then turned into more tangible, wooden prototypes made with the laser cutter. (the yellow lines illustrate how they would be used and the relationship between items)

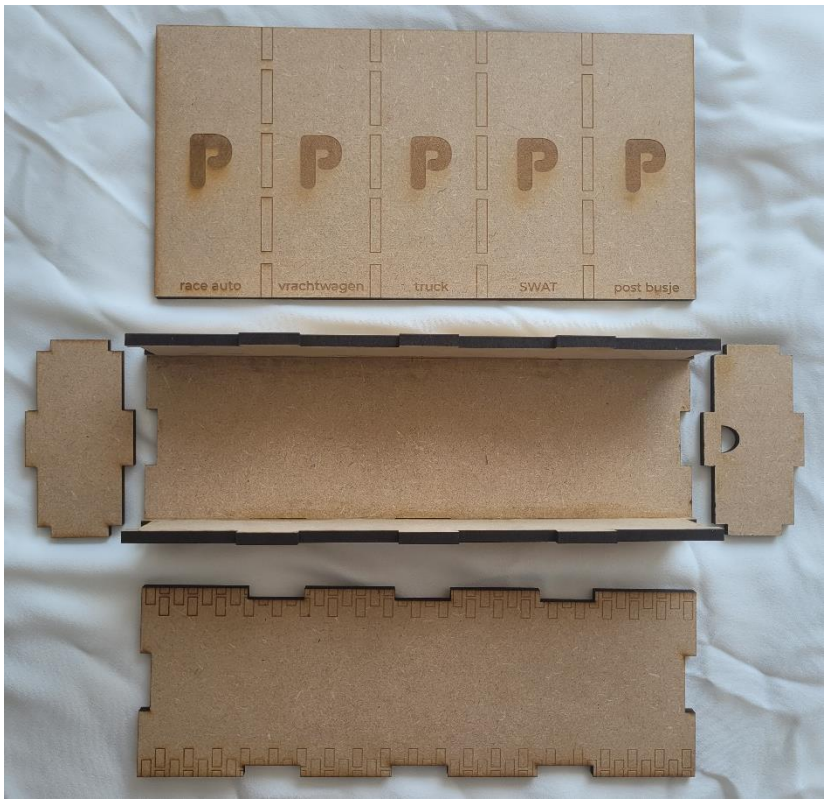




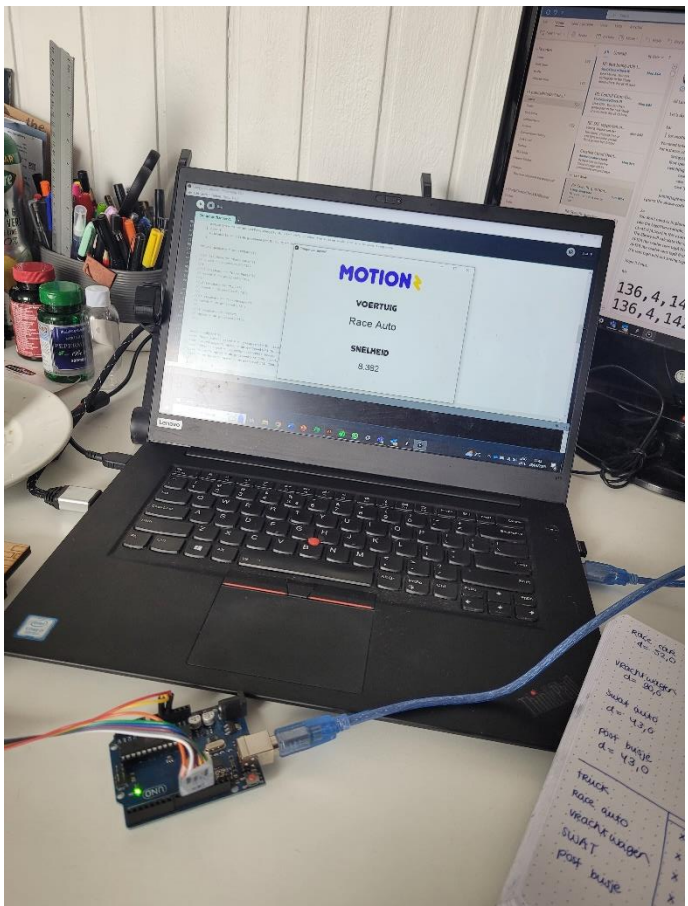


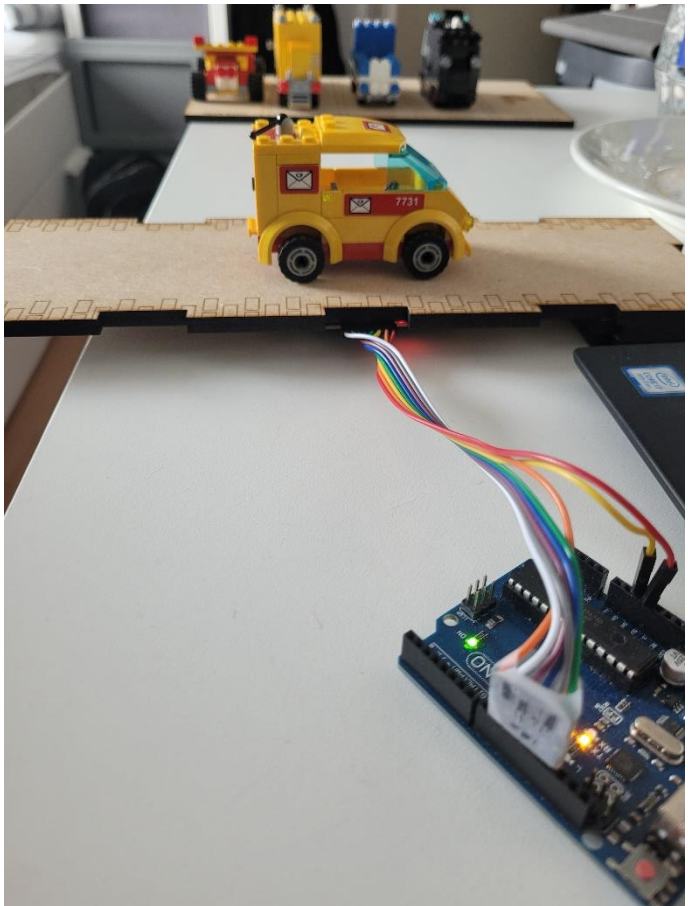
Design Probe Version 1

After the physics topic was chosen, the first version of the design probe was created. Calculations were made first for the specs of the prototype after it was laser cut on wood and assembled together.



This first version was also used to test out the NFC tags and scanner in this kind of setup. The code was then also adapted to the needs of the project and a simplified screen was designed as interface.





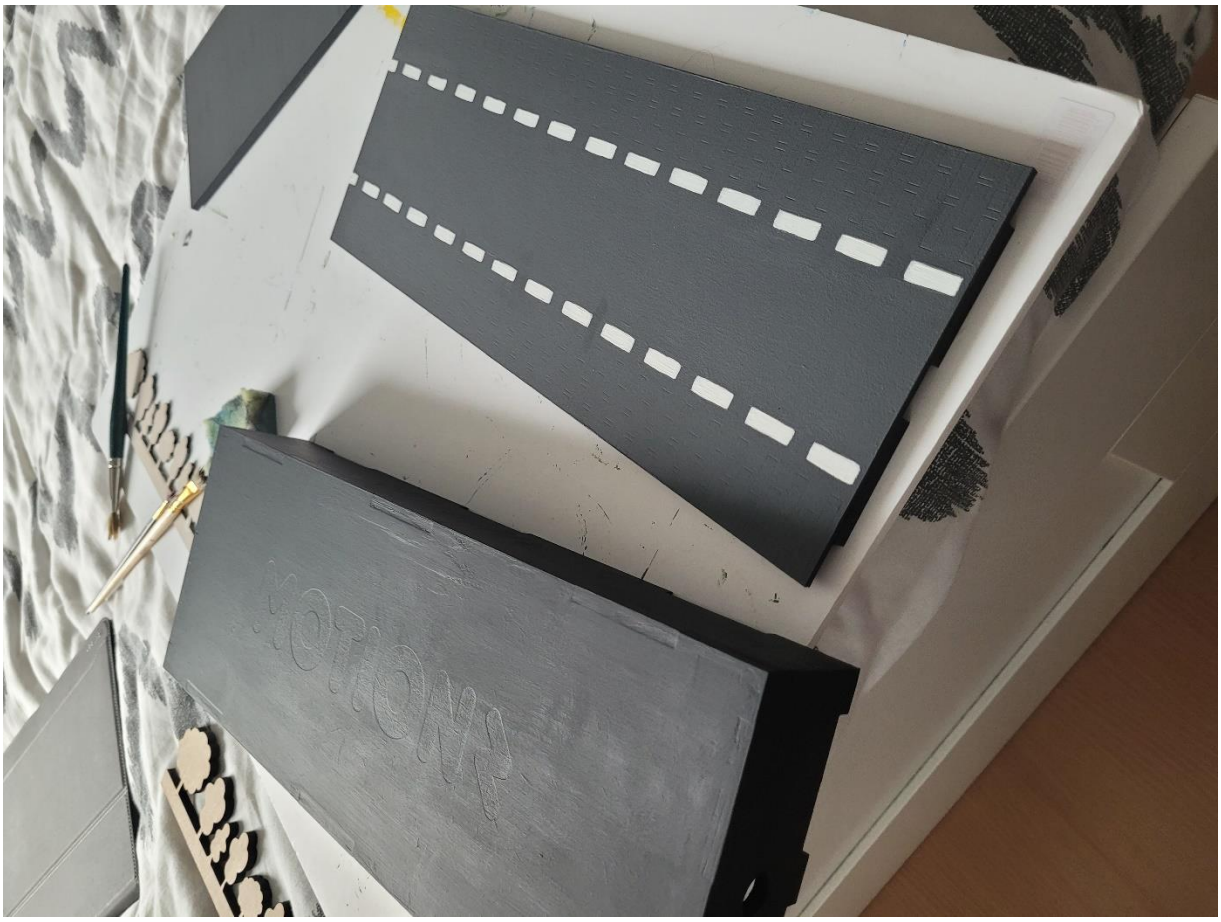
Design Probe Version 2

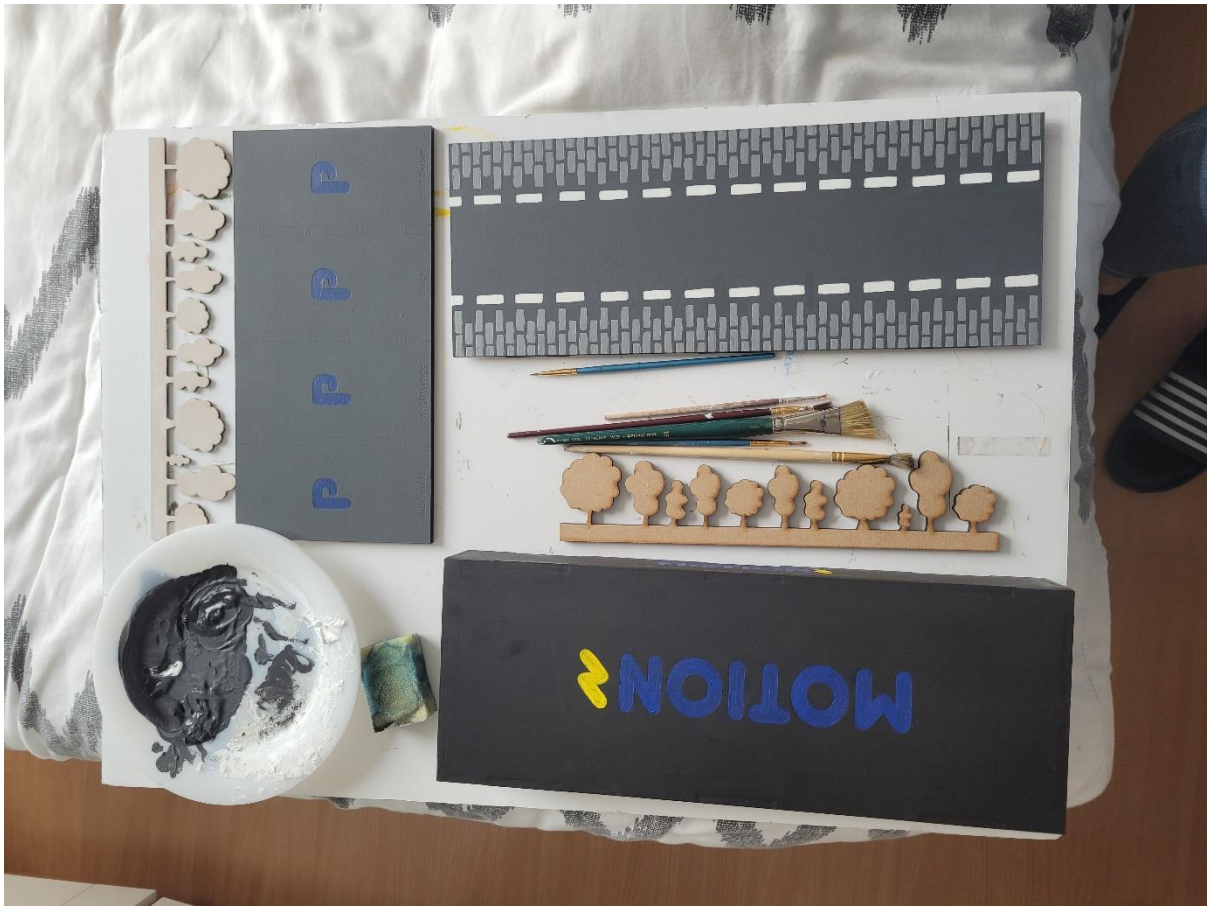
Several improvements (from both own experience) already needed to be made to the new version of the design probe. So another one was made immediately after. This version was also painted with the branding colors to figure out the desired aesthetic of the prototype.

This prototype was also tested with the first two LEGO vehicles that were created.

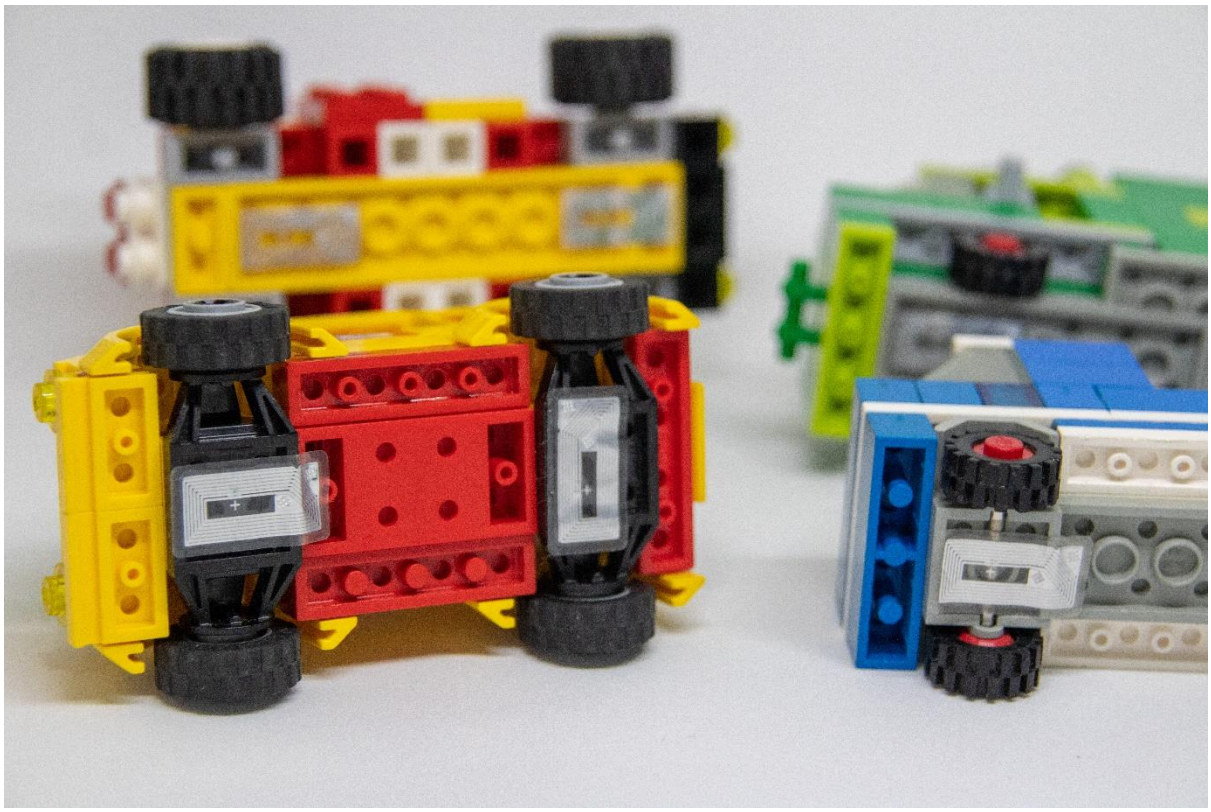
Design Probe Version 3 – final design

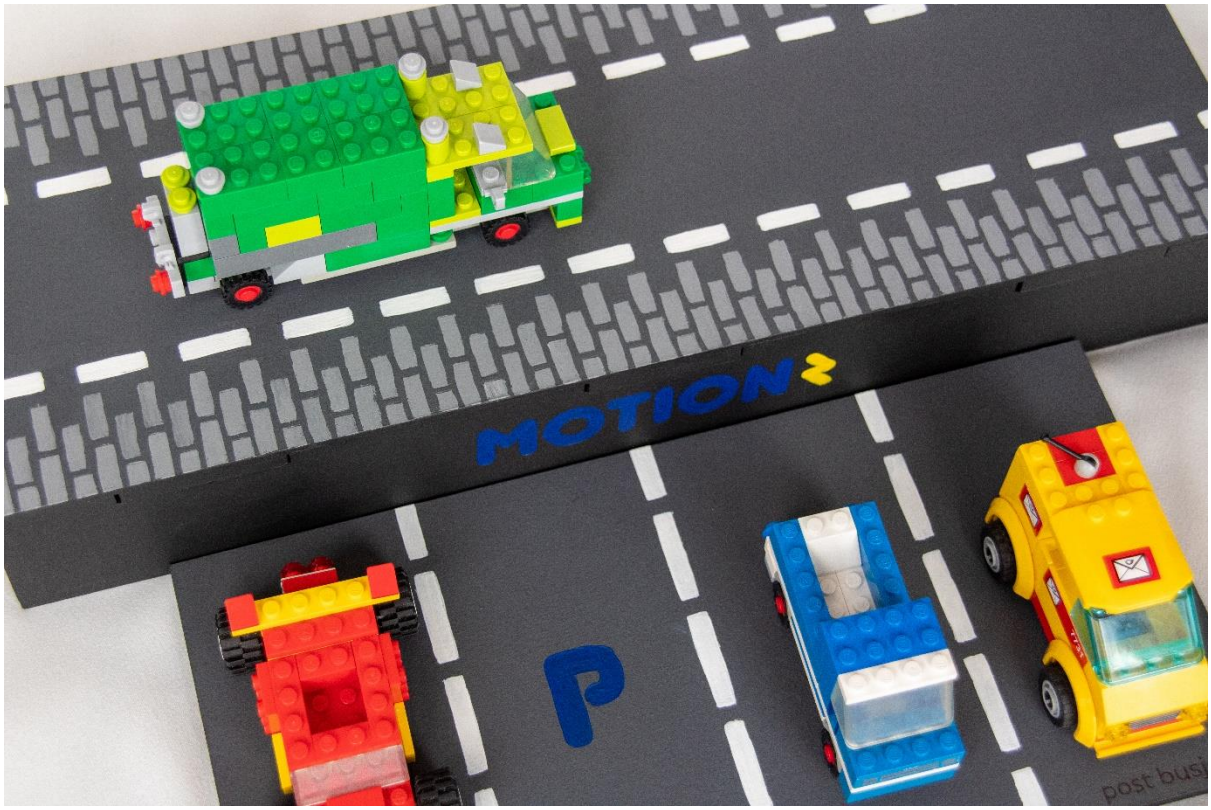
After Version 2 was used for a designer review, several suggestions were made and improvements were needed. A new version was created (you can see part of the process and the final results).



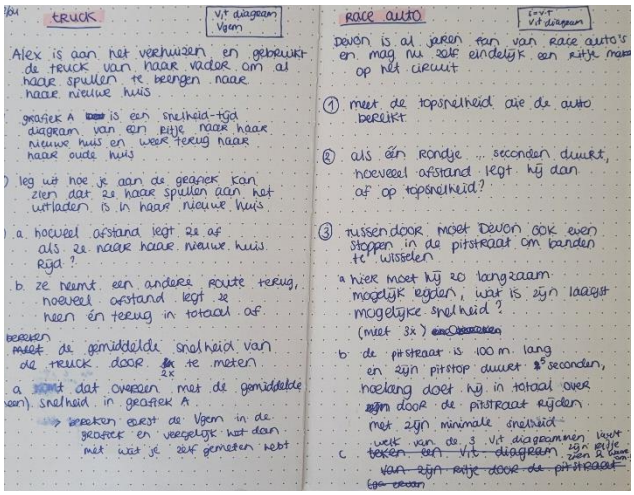



truck
vrachtwagen
post busje





During the creation of the final design, the worksheets were also designed per vehicle. Initial exercises were created based on the different vehicles and then they were turned into worksheets to complete the design process of MOTIONz and make it ready for testing.



Appendix C – ERB Form

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Ethical Review Form

(Version 1.6)

This Ethical Review Form should be completed for every research study that involves human participants or personally identifiable personal data and should be submitted to ethics@tue.nl. For more information about how this process works please click here.

Part 1: General Study Information		
1	Project title	Application of Emerging Technologies in Secondary Education Physics
2	Name of the researcher/student	L.Y. Smits
3	Email of the researcher/student	l.y.smits@student.tue.nl
4	Supervisor(s) name(s) *Additional explanation: Please write down the name of your direct supervisor. You can mention several supervisors if appropriate, but at least one supervisor should be mentioned.*	Prof. dr. ir. M.M. (Tilde) Bekker
5	Supervisor(s) email address(es) *Additional explanation: Please give the email address of the supervisor(s) mentioned in question 4.*	m.m.bekker@tue.nl
6	Department	Industrial Design
7	Are you a student and is this application for educational purposes?	☐ Yes, Bachelor. Course: ☒ Yes, Master. Course: DPM120 (Project 2) ☐ No
8	Research location *Additional explanation: Where will the data collection take place? On campus, in a company, in public space, etc.*	the Netherlands
9	Start date data collection *Additional explanation: Please state when your data collection will start. Please note that you do not have to provide information about your complete (PhD) project, but only on this particular sub-study that you are submitting for approval in this form.*	17/05/2023
10	End date data collection	01/08/2023
11	Does your project receive external funding (e.g., NWO, relevant for special regulations from funders)?	☐ Yes. Name Funder: ☒ No
12	Which internal and external parties are involved in the study? Think about sharing data or information between TU/e and other universities, commercial companies, hospitals, etc. *Additional explanation: Describe all internal and external parties that are involved in the study or project, including:* • *human participants (e.g., people being interviewed, people participating in online surveys, patients, etc.);* • *researchers or research groups at the TU/e who participate in the study;* • *(Researchers at) other universities/institutions that provide data/services, help analyzing the data, etc.;* • *(commercial) partners, companies, government bodies, municipalities, consultancy firms, hospitals or care institutions that provide data (e.g., contact details of participants, data for further analysis).*	*Internal Parties:* - My supervisor; Tilde Bekker o Tilde coaches me on my project, guides my research and will have access to the processed data. She will not be able to get access to the raw data. - My assessors, which are to be determined towards the end of the project and will consists of people from the Industrial Design department o My assessors will have access to the paper created with/based on this data and are able to request the processed/analysed data used in the research paper which is used to grade my research project. They will not be able to get access to the raw data.

Ethical Review Form

	Indicate which role each party plays: who defines the means and purposes in the study, who will supply the data (external parties?), who will process/handle the data, who will be able to access the data during and after research (only researchers at TU/e or also others)?	*External Parties:* - The Educators o The teacher and/or other people from the school will have the opportunity to get access to the processed/analysed data if they wish so. This will be on request basis and they will not be able to get access to the raw data.
13	Have any special agreements already been made with an external party, such as a Non-Disclosure Agreement (NDA) or a data sharing agreement?	☐ Yes, namely: ☒ No
14	Has your proposal already been approved by an external Ethical Review Board or Medical Ethical Review Board? *Additional explanation: For example, when you are collaborating with another university and the project has been approved by their Ethical Review Board, or when you received a WMO-waiver from a Medical Ethical Review Board.*	☐ Yes ☒ No
15	If yes: Please provide the name, date of approval and contact details of the ERB. Please also include the registered number for your project approval. Additionally, please send in the Ethical Review Form upon which ethical approval was granted together with this form.	-
16	Have you already performed a Data Protection Impact Assessment (DPIA) for this or a very similar project? ***Please read the information below: a DPIA is not the same as a regular privacy impact assessment. More detailed questions on privacy will follow in the section below.*** *Additional explanation: A Data Protection Impact Assessment (DPIA) is a formal document that must be drafted under the guidelines of the General Data Protection Regulation (GDPR)* ***if you process personal data that are likely to result in high privacy risks for participants.*** *Think of research with vulnerable people, high-risk medical research, The Dutch DPA (Autoriteit Persoonsgegevens) and our website provides more information about a DPIA.*	☐ Yes ☒ No If yes: Please provide details about the DPIA here and send in the DPIA documentation together with this form.
	Part 2: Medical study	
1	Does the study have a medical scientific research question or claim? *Additional explanation: Medical/scientific research is research which is carried out with the aim of finding answers to a question in the field of illness and health (etiology, pathogenesis, signs/symptoms, diagnosis, prevention, outcome or treatment of illness), by systematically collecting and analyzing data. The research is carried out with the intention of contributing to medical knowledge which can also be applied to populations outside of the direct research population. If your research contains*	☐ Yes* ☒ No *If yes or in doubt, please contact Susan Hommerson via s.m.hommerson@tue.nl

Ethical Review Form

	questions about health and health related parameters (such as well-being, vitality, feelings of anxiety or stress) but your research question is not primarily medical, then you can answer 'no' to this question.	
Part 3: Use of (medical) devices in the study		
1	Does your research include a device? *Additional explanation: A device is a complete piece of physical hardware that is used to compute or support computer functions within a larger system. Devices can be divided into input-, output-, storage-, internet of things-, or mobile device.*	☐ Yes, not self-made ☒ Yes, self-made ☐ No
2	Please describe your device or link to an online description of the device	In the appendix is a full description of the concept and links to the technology used. The technology used is however not self-made and will be implemented in the design itself. The technology is already published and included in several published studies by Rong-Hao Liang and others.
3	Will you use a device that is 'CE' certified for **unintended use** (meaning you will use existing CE certified devices for other things than they were originally intended for) or use a device that is not 'CE' certified? *Additional explanation: You can find more information about CE certification on https://ec.europa.eu/growth/single-market/ce-marking_en.*	☐ Yes ☒ No
4	If yes: Do you use a device or software that has a medical purpose such as diagnosis, prevention, monitoring, prediction, prognosis, treatment or alleviation of disease or injury?	☐ Yes, my device or software currently has a medical purpose ☐ Yes, my device or software could have a medical purpose in the near future ☒ No ☐ I'm not sure
Part 4: Information about the study		
1	What are your main research questions? *Additional explanation: You need to provide at least one clear research question.*	How is the design probe experienced by physics educators? How suitable is the design probe for education?
2	Description of the research method *Additional explanation: For example, interview, survey, experiment, user-test, Randomized Experiment, focus groups, pilot study, observation, etc.*	Usability testing will be done to determine the effectiveness, efficiency and satisfaction of the design. Participants will be asked to finish a simple task and do a post-questionnaire on satisfaction as well as a small semi-structured interview.
3	Description of the research population, in- and exclusion criteria *Additional explanation: Please describe which persons are eligible for your study. What criteria are used to select participants in your study, and what criteria are used to exclude possible participants?* *For example: We will randomly select participants from the JSF participant database with good vision and older than 18 years.*	Inclusion criteria: - Secondary Education Educator - Teaches physics or similar named course o Sometimes courses are combined which include physics and another STEM course, those are also acceptable - Able to understand Dutch & English Exclusion criteria: - Under the age of 18

Ethical Review Form

		- Teachers in training
4	Description of the measurements and/or stimuli/treatments *Additional explanation: Think about your outcome measures and the variables you will be collecting and describe them in a way such that another person understands what the participant will experience. For example: Participants will perform task A and see pictures from database B, and we measure validated Scale 1.*	The participants will be asked to interact with the design (see appendix for description) in order to understand their experience and the usefulness of it. The goal is to be able to understand how tangible tools in current secondary education curriculums are experienced. They will be asked to interact with the design probe and solve challenges designed to replace traditional (boring) physics exercises. The design probe used in this study consists of a technology designed and published by Rong-Hao Liang called NFCsense. It's a technology that allows NFC tags be given different material properties which can be scanned by a NFC scanner and displayed on a screen. This technology will be used to create a physical and tangible version of real world physics concepts (like movement and sound). The researcher will only design with the technology and create an application for physics, so no changes to the technology are made and thus it is deemed same to use. The types of measurements in this study (can) include: observation notes, survey answers, audio recordings of interviews and pictures of the interaction with the design probe. *All of these measurements will not include any identifiable characteristics, ensuring their privacy is respected and they are safely participating in this study. Any possible identifiers will be deleted from the raw data during the processing. Audio recordings will also be transcribed in this process after which they are deleted.*
5	Describe and justify the number of participants you need for this study. Also justify the number of observations you need, taking into account the risks and benefits. *Additional explanation: Think about if you need 3 or 30 participants for example, and why? Do they need to provide their input once, or several times, and why?*	3-10 physics educators
6	Explain why your research is societally important. What benefits and harm to society may result from the study? *Additional explanation: What benefit will the results of your study have to society in general?*	*Social Importance* In the context of teaching students 21st century skills, it is important to empower students to take control of their own learning process. Providing tools that allow them to do this will increase the chance that students can take control of their learning process (OECD , 2018). Today's secondary school education is quite often determined almost fully by the teacher, with that we mean that students have limited influence on their own learning experience/process. To help students feel more empowerment, looking into how to create more ownership within the boundaries of the offered education is crucial. *Benefits* The benefits of this study mainly include the knowledge to be able to understand the role, purpose and result of using a design probe including emerging technologies in current secondary education. This knowledge can then be translated to design requirements or similar tools used to be able to design valuable and useful educational materials.

		Benefit Educators The educators will value from this research on an educational basis. The study has an educational purpose and the design probe is designed to that effect as well. The goal is to get them to experience tools that might be able to assist them in their lessons which can improve and innovate their education in the future. *Harms* We view there is little to no harm for society as the current research will try to fit in with the current educational system and not be too disruptive. (OECD, 2018) Education 2030: The Future of Education and Skills. Position Paper, https://www.oecd.org/education/2030/E2030%20Position%20Paper%20(05.04.2018).pdf
7	Describe the way participants will be recruited *Additional explanation: How will you recruit participants for your study? For example, by using flyers, personal network, panels, etc.*	Participants will be recruited through the professional network of the researcher. Contacting current contacts in secondary education will be used to reach out to multiple schools and physics teachers.
8	Provide a brief statement of the risks you expect for the participants or others involved in the study and explain. Also take into consideration any personal data you may gather and associated privacy issues. *Additional explanation: Risks for the participants can be anything from risk of data breach to risk of safety or well-being. Describe these possible risks and describe the way these risks are mitigated.*	The researcher will collect all data without personal identifiers. All the raw data will be pseudonymized after which the raw data is deleted to make sure it is safe. **Risk** The risks are deemed negligible as the purpose of the study is educational and designed with this in mind. They will not be asked to engage and interact with anything that is not safe. **Data collection and storage** All the participants will be informed about the research activities before the study, including the data collection, storage, and usage protocols. The gathered (raw) data is only accessible to the researcher when the participants give consent. Moreover, from the data that occurs during the study, only data that is necessary for the study will be used. After the raw data is gathered, the data will be processed within 1-2 weeks and deleted. All the raw data will be pseudonymized by using participant ID (random number) and deleting all personal information that can be traced. After this process, the data will be known as 'processed' data. All the data (survey answers, notes, comments, audio recordings) will be stored locally on the researcher laptop and/or phone until six months after the end of the project: 1st of March 2023 and deleted after that period. Both devices are password protected. Observation notes will be documented in the notebook of the researcher and only accessible to them.

		The participants can decline their participation and results at any given moment during the study, when this is the case, the data will be destroyed and not be used.

Part 5: Self-assessment checklist

	Note: answers in the blue boxes indicate that your research is eligible for fast-track approval	Yes	No
1a	Does the study involve human material? (e.g., surgery waste material derived from non-commercial organizations such as hospitals)		x
1b	Will blood or other (bio)samples be obtained from participants? (e.g., hair, sweat, urine or other bodily fluids or secretions, also external imaging of the body)		x
2	Will the participants give their consent – on a voluntary basis – either digitally or on paper? Or have they given consent in the past for the purpose of education or for re-use in line with the current research question?	x	
3	Are the participants, outside the context of the research, in a dependent or subordinate position to the investigator? *Additional explanation: Think about doing research on your own students or on your own employees. When there is a dependency or power imbalance between you and the research participants, you need to answer 'yes' to this question.*		x
4	Does the study involve participants who are particularly vulnerable or unable to give informed consent? (e.g., children (<16 years of age), people with learning difficulties, patients, people receiving counselling, people living in care or nursing homes, people recruited through self-help groups)		x
5	Will participating in the research be burdensome? (e.g., requiring participants to wear a device 24/7 for several weeks, to fill in questionnaires for hours, to travel long distances to a research location, to be interviewed multiple times)?		x
6	May the research procedure cause harm or discomfort to the participant in any way? (e.g., causing pain or more than mild discomfort, stress, anxiety or by administering drinks, foods, drugs, or showing explicit visual material)		x
7	Will financial inducement (other than reasonable expenses and compensation for time) be offered to participants? *Additional explanation: For an explanation of what is considered a reasonable compensation, see the topic participant fees from the HTI group*		x
8a	Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (e.g., covert observation of people)		x
8b	If yes: Will you be observing people without their knowledge in public space? (e.g. on the street, at a bus-stop)		-
9	Will the study involve actively deceiving the participants? (e.g., will participants be deliberately falsely informed, will information be withheld from them, or will they be misled in such a way that they are likely to object or show unease when debriefed about the study)		x
10	Will participants be asked to discuss or report sexual experiences, religion, alcohol or drug use, suicidal thoughts, or other topics that are highly personal or intimate? *Additional explanation: Think about your research population. For some participants, particular topics can be considered sensitive or intimate, whereas the same topics will not be perceived as such by other participants.*		x
11	**Elaborate on all boxes answered outside of the blue boxes in part 5. Describe how you safeguard any potential risk for the research participant.**		

Part 6: Self-assessment on privacy

The following questions (1-10) concern privacy issues, as laid down in the General Data Protection Regulation (GDPR). The Data Stewards and – if necessary – privacy team of TU/e will assess these questions. In some cases, more information is required to assess the privacy risks. If this is the case, you will be notified that the Data Stewards team will contact you.

The GDPR defines 'personal data' as any information relating to an identified or identifiable natural person ('data subject'). Personal data also includes data that indirectly reveals something about a natural person. Personal data can lead to the physical, physiological, genetic, mental, economic, cultural or social identity of a natural person. There are two main categories of personal data: regular personal data and special category personal data.

If you are not sure whether some of these questions below should be answered with a Yes or No, please contact a Data Steward first through rdmsupport@tue.nl.

	Note: answers in the blue boxes indicate that your research is eligible for fast-track approval	Yes	No
1	Will the study involve discussion/collection/processing of **regular** personal data, or will you collect and (temporarily) store video or voice recordings for the purpose of conducting interviews? *Additional explanation: For example, name, address, phone number, email address, IP address, gender, age, video or interview recordings? If you are not sure whether your data contains personal data, please contact the Data Stewards Team (rdmsupport@tue.nl).*	x	
1A	If yes: Please describe which regular personal data you will collect in this study?	Audio recordings will be made during interviews and will be temporarily be stored on the researchers devices after which they are to be deleted after processing (transcribing and analysis). Pictures will *not* include any personal data but only unidentifiable characteristics such as hands, arms, back of heads etc. The signed consent forms will include personal data like their names and signatures but will be stored safely in the researchers home. These signed forms will not be linked to specific individuals, therefore it will not be possible to link the answers from interviews to specific people for instance.	
2	Will the study involve discussion/collection/processing of **special category** personal data or other **sensitive data**? *Additional explanation: Examples of special category personal data are race, religion, health information, political views, genetic or biometric data for the unique identification of a person, sexual preference, etc. Health information concerns personal data of the physical or mental health of persons, including the provision of health care. Examples of other sensitive data is information such as communication data, financial records or credit scores, camera surveillance data, location/GPS data, internet-of-things data, employee monitoring, observing or influencing behaviour, criminal records, data of vulnerable persons (children, people with disabilities, refugees), BSN number etc. Please be aware that the use of special category personal data in research requires extra security measurements in order to safeguard the privacy of data subjects and to comply with the GDPR. Processing of this special category data is prohibited, except for specific purposes and under certain circumstances. If you need to process special category data, please consult the data stewards at rdmsupport@tue.nl.*		x
2A	If yes: Please describe which special-category personal data and/or sensitive data you will collect in this study?	-	

Ethical Review Form

If you answered yes to either question 1 or 2, please answer the questions below. If you answered no to both questions, you can skip this part and continue onto part 6. Also, if an answer to any of the following questions is 'yes', please contact a Data Steward at rdmsupport@tue.nl

		Yes	No
3	Will your project involve the processing of personal data on a **large scale**? *Additional explanation: In general, any processing that involves more than 10.000 data subjects should be considered "large scale". However, if the data of approximately 1000 persons (or more) are involved, the data processing may still be considered large scale. In that case, besides the number of persons involved in the study, one should also assess (i) the amount of data collected from these persons taking into account the type/risk level of the personal data, (ii) the duration of the data processing, (iii) the geographic scope or extent of the processing. For example, if you would collect and process data across several European countries with 10+ socio-economic data items of 1200 individual persons for several years in a row, that is likely "large-scale processing". Other examples of a large-scale processing activity are:* • *Monitoring driving behavior of road users on Dutch highways* • *Collecting data of Covid patients* • *A hospital that processes patient data as part of its usual operations* • *A transport company that processes travel information of people who travel by public transport in a certain city. For example, by tracking them through travel maps.*		x
4	Does this processing activity involve the use of new or innovative technologies? *Examples of a new technology: combining fingerprints and facial recognition for physical access control, the use of bodycams in public spaces, the use of new technical methods in conducting research such as AI. This question also refers to new technologies that have not been deployed by TU/e so far.*		x
5	Does your study involve systematic (c.q. automated) monitoring of persons? *Additional explanation: Consider data processing activities that have the purpose of observing, monitoring or controlling individuals, for example in circumstances where the individuals are not aware by whom their personal data is collected and how it is used. Examples of such activities are using camera systems to monitor driving behavior on highways, monitoring email inactivity or employee phone use, certain applications of machine learning and artificial intelligence.*		x
6	Does the study involve collaborations (with third parties) in which data are shared or exchanged in order to link or combine data? *Additional explanation: This may often apply in a collaboration between the university and a commercial party, contract research, etc. It is important to assess this for all data in the entire project, not just your own data.* *An important consideration in this situation is whether the person whose data is involved could have expected that data from these different databases or sources of information were to be combined. For example, it is less likely for data subjects to expect that databases from different parties will be combined and the results are used for different purposes than one could reasonably expect; this may apply for example in a collaboration between the university and a commercial party.*		x
7	Will the study include data processing activities that prevent data subjects from exercising their rights or using a service or contract? *Additional explanation: Examples include processing operations carried out in public places that people cannot avoid (train station, airport, shopping mall, public university premises, etc.) or processing operations whose purpose is to allow or not allow data subjects to use a service or enter into a contract (examples: by refusing to pay a benefit, not being able to apply for a loan, etc.).*		x
8	Will the study process personal data to score, rank or profile persons? *Additional explanation: Examples: monitoring (highway) roads to give road users a "score" based on their detected driving behavior, a bank assessing its customers based on their creditworthiness, or an organization building behavioral and marketing profiles based on use of their website or navigating their website.*		x
8	Does your data processing include activities that involves composing "**blacklists**" – and, in particular, in relation to sensitive or special category data, such as communication data, financial records or credit scores, genetic data, biometric data, health data, camera surveillance data, location/GPS data, internet-of-things data, employee monitoring, observing or influencing behaviour, etc. *Additional explanation: This situation will not be a common occurrence in research, but you may indirectly be involved in this. In general, this typically concerns processing operations involving personal data relating to criminal convictions and offences, data relating to unlawful acts, data concerning unlawful or annoying behaviour or data concerning bad payment behaviour by companies or individuals are processed and shared with third parties (blacklists or warning lists, as used, for example, by insurers, hospitality companies shopping companies, telecom providers as well as blacklists relating to unlawful behavior of employees, for example in the healthcare sector or by employment agencies, etc.).*		x

9	Will personal data be transferred or shared outside the EU/EEA? EU data protection rules apply to the European Economic Area (EEA), which includes all EU countries and non-EU countries Iceland, Liechtenstein and Norway. *Additional explanation: The GDPR has drafted additional requirements for transfers data outside of the EU/EEA. Typically, additional safeguards must be implemented to protect the personal data of residents in the European Union. For example, if you collaborate with an American, Indian or Chinese university or other third party outside the EU/EEA, you must first check whether this is allowed and under which conditions this is allowed. Another typical example is storage of data on American providers of cloud (storage) services. Please contact the data stewards first to discuss this.*		x
10	Will any raw or anonymized personal data or any other sensitive data or research results from the project possibly be transferred to a high-risk country*? ***High risk countries**: China, Russia, Iran, Turkey, and North Korea.* *If personal data or other potentially sensitive data is exchanged with one of these countries, or if part of the data processing takes place in one of these countries: **an advice from the Data Protection Officer, the kennisveiligheidsteam (Knowledge Security team), and the CISO (Chief Information Security Officer) is ALWAYS required.***		x

Part 7: Data processing, storing and archiving

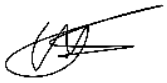
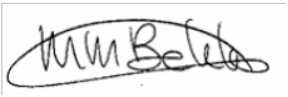
1a	Is consent your legal basis for processing the personal data in your study? *Additional explanation: What is a legal basis? One of main principles in the GDPR is to ensure that personal data is processed lawfully, fairly, and transparently. To comply with this principle, the processing of personal data also requires that you have a valid legal basis for the personal data processing activity.* *In research projects, the legal basis is often but not always consent. However, it is possible that it is not clear or not possible to establish whether to use consent as a legal basis.* *Some examples where consent may not be applicable as legal basis are covert research, data collection in public spaces, secondary data analysis of existing data, data that are transferred to you by a third party, consent is not possible or would require disproportionate effort, etc. In that case, please indicate which legal basis you think that applies or (preferably) contact a data steward first.*	☒ Yes ☐ No
1b	If yes: Please briefly explain how you will obtain consent from participants and send in your draft of the information letter and consent statement together with this form. You can download a suitable template here.	The participants will be asked to complete the informed consent form and be given the opportunity to voice their questions to researcher before participation.
1c	If no: Please briefly explain on which legal basis - other than consent - you will process the personal data in your study.	-
2	In which way will you collect and process the (personal) data? *Additional explanation: Please describe which software (e.g., LimeSurvey, Atlas Ti, Qualtrics), tools (electronic lab journals, information management systems, etc.), technologies, apps or devices (Internet-of-Things, Fitbit, etc.), techniques (monitoring, interview, survey), special data environments (e.g., Living Lab), etc. you will use to collect or process data?*	
3	Where will the data and in particular the personal data be stored during and after completion of the study? If you have already uploaded your Data Management Plan, you can refer to your Data Management Plan. *Additional explanation: Please address the following:* • *Where will you store your data during the study and after you have completed the study? University supported-storage facilities are SURFdrive, SURF Research Drive, Ceph, departmental drives (this includes BE Project Drive), and the TU/e instance of Microsoft OneDrive. For most personal data, the use of SURF Research Drive, departmental drives (including BE Project Drive) and SURFdrive is required.*	

4	Which security measures are applied? *Additional explanation: Please address these questions:* • *Is access to your (personal) data restricted? If yes, how (access control, password protection, etc.)?* • *Who will have access to the data during and after completion of the study?* • *Will you anonymize or pseudonymize the data?* • *Is Bitlocker (Windows), FileVault (Mac) or similar hard-drive encryption active on your laptop?* • *What will you do with the data after your project has come to results? Do you need to keep all data?* • *How long will you store the data after completion of the project, or can/will (part of) the data be destroyed?* • *Will you or your supervisor want to keep the data for new or future research/reuse? Will you share (raw) data with others? If yes, how and how do you ensure that this is secure?* • *If access restrictions are required during and after the study, please explain how this is arranged.*	The data used will be pseudonymized by assigning each participant to a number. The data itself does not include any personal data. The consent forms will be stored until 6 months after the study is completed and then destroyed. Nobody except the researcher will have access to this and it will be stored safely and securely in the researchers home. The pictures from the interaction with the design probe will only include unidentifiable characteristics (hands, arms, etc.) are therefore not including any personal data. After the completion of the project, the data will be stored up to 6 months after the end of the study for potential follow-up studies/projects. This stored data will only include the processed and pseudonymized data. This data will be stored on the researchers laptop and/or Microsoft OneDrive/Teams. The people who will have access to the data in processed form are described in a section earlier in this document. If the project continues by other people and/or my supervisor, only the processed data will be accessible. Nobody, other than the researcher, will have access to the raw data as this is destroyed upon processing (e.g. taking out sensitive information). Processed data will only be transferred via university used software (e.g. Microsoft Teams and/or Outlook) to make sure it is safely shared.

Part 8: Closures and Signatures

1	Enclosures (tick if applicable): ☒ Informed consent form; ☐ Informed consent form for other agencies when the research is conducted at a location (such as a school); ☐ Text used for ads (to find participants); ☐ Text used for debriefings; ☐ Approval other research ethics committee; ☐ The survey the participants need to complete, or a description of other measurements; ☒ Any other information which might be relevant for decision making by ERB; ☐ Data Protection Impact Assessment checked by the privacy officer	- Informed consent form - System Usability Scale (to be used for measuring user satisfaction) - Description of the design probe and technology used

Ethical Review Form

	☐ Data Management Plan checked by a data steward	
2	Signature(s) Signature(s) of researcher(s) Date: 21/05/2023 Signature research supervisor (if applicable) Date: 22/05/2023	 

Appendix A: Informed Consent Form

Informed consent form

This informed consent form before you entail the details of voluntary participation in a study where you are asked to interact with the prototype and talk about your experience with it and its potential for future use in secondary STEM education.

- I have read and understood the information of the corresponding information form for participants.
- I have been given the opportunity to ask questions. My questions are sufficiently answered, and I had sufficient time to decide whether I participate.
- I know that only the researcher (Laure Smits) has access to the data and that the data will be stored locally for six months after the study.
- I know that my participation is completely voluntary. I know that I can refuse participation and that I can stop participation at any time during the study, without giving any reasons. I know that I can withdraw permission to use the data at any given moment during the study.
- I agree with the voluntary participation of me in this study.
- I agree with the fact that this session is audio-recorded which is to be used for analysis afterwards.
- I know that no information that can be used to personally identify or my responses in this study will be shared with anyone outside of the research team.

Certificate of consent

I, (NAME) ……
want and provide consent to participate in this study.

Signature here

Appendix B: System Usability Scale

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

Appendix B: Explanation Concept Design/Probe

The full design/probe is still in development, however it is possible to present the concept including the technology to be used in this study.

The design was created to help with the topic Movement within secondary school physics (or similar named courses). Upon the students introduction to the topic, they often are asked to do a series of exercises where they repeatedly use the formula s=v*t and similar in different contexts. The probe was designed to make this process more fun, motivational and engaging and to see in this study if that is actually the case.

The design includes technology created by Rong-Hao Liang. His publications and videos to show how the technology works are found here:

Link to published research paper: https://dl.acm.org/doi/10.1145/3411764.3445214

ACM reference:

Rong-Hao Liang and Zengrong Guo. 2021. NFCSense: Data-Defined Rich-ID Motion Sensing for Fluent Tangible Interaction Using a Commodity NFC Reader. In Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21). Association for Computing Machinery, New York, NY, USA, Article 505, 1–14. https://doi.org/10.1145/3411764.3445214

Links to videos about the paper/technology:
https://www.youtube.com/watch?v=_xslMnz1Ve4
https://www.youtube.com/watch?v=eP5Va8Ba3Co
https://www.youtube.com/watch?v=BnU6xsbqqMw

He uses NFC tags and gives them special properties which makes him able to register all types of things when objects are labeled with an NFC. With an NFC scanner or special screen (that has an integrated scanner), he is able to measure things like velocity, frequency, order of objects, placement and more. This was used to create the following concept which will be turned into a interactive prototype to be used in this study (see next page). The image aims to illustrate how the design to be used will look like. The NFC tags and scanner are the emerging technology used in this study together with the library Rong-Hao Liang created. These are already published items and are deemed safe to use in the conditions of this study as NFC tags are not able to harm children in any likely way.

The design will feature several 3D representations of moveable objects such as cars, bikes, motor, limo, tractor and more. The other component will feature an NFC scanner in the form of one or more road systems (like a neighborhood, a racetrack, a highway or similar). This combination allows students to explore concepts like velocity, maximum distance or time during movement in a tangible and hands-on way.

The design can be seen on the next page.

This is a picture of the current design which will be used during this study.

Appendix D – Educator Consent Form

Informed consent form

This informed consent form before you entail the details of voluntary participation in a study where you are asked to interact with the prototype and talk about your experience with it and its potential for future use in secondary STEM education.

- I have read and understood the information of the corresponding information form for participants.
- I have been given the opportunity to ask questions. My questions are sufficiently answered, and I had sufficient time to decide whether I participate.
- I know that only the researcher (Laure Smits) has access to the data and that the data will be stored locally for six months after the study.
- I know that my participation is completely voluntary. I know that I can refuse participation and that I can stop participation at any time during the study, without giving any reasons. I know that I can withdraw permission to use the data at any given moment during the study.
- I agree with the voluntary participation of me in this study.
- I agree with the fact that this session is audio-recorded which is to be used for analysis afterwards.
- I know that no information that can be used to personally identify or my responses in this study will be shared with anyone outside of the research team.

Certificate of consent

I, (NAME)
……
want and provide consent to participate in this study.

Appendix E – Full Research Session Set-Up

Deel 1: Informele Introductie

-

Deel 2: Ondertekenen Consent Form

Laat deelnemers de consent form ondertekenen.

Deel 3: Officiële Introductie (lees dit voor)

Heel erg bedankt voor het meewerken aan dit deel van mijn onderzoek. Zoals al eerder toegelicht is dit deel gewijd aan het testen van het product dat ik heb ontworpen, hierbij ben ik benieuwd naar wat jullie ervaring hiermee is en de geschiktheid van zulke producten in het onderwijs.

Dit is MOTIONz, een product ontworpen voor het natuurkunde onderwerp: beweging. Het doel van het product is om experimenteel leren naar het klaslokaal te brengen zodat leerlingen hands-on kunnen leren over de verschillende concepten en theorieën binnen beweging. Deze versie is gericht op onderbouw HAVO/VWO leerlingen die aan de hand van een aantal werkbladen aan de slag kunnen met de stof waar ze over leren. Hier is dan ruimte voor spelenderwijs en experimenteel leren door kleine experimentjes na te bootsen op kleine schaal.

MOTIONz bestaat uit een aantal onderdelen; de voertuigen, de parkeerplaats waar ze opgesteld staan en het snelheidstraject. Het snelheidstraject is in staat om de snelheid te meten van de voertuigen die over het traject worden bewogen en geven dat weer op het scherm. Omdat het traject maar op kleine schaal de snelheid meet, zie je op het scherm straks twee snelheden. Eentje is de snelheid die de sensor meet en de ander laat zien wat die snelheid zou zijn in de echte wereld, hij rekent het dus voor ons om. Die omgerekende waardes gebruik je ook in je opdrachten.

Je kan de voertuigen bewegen over het traject om te zien wat de snelheid is. De werkbladen geven je opdrachten per voertuig waarmee je aan de slag kan gaan met experimenteel en hands-on leren. Je krijgt voor deze sessie de opdrachten over de rode raceauto. Na het afronden van de opdracht kan je ook nog door de rest van de werkbladen kijken waarna we doorgaan met de questionnaires en mini interview.

Deel 4: Usability Testing (15 min) (maak foto's!)

1. Geef de deelnemers het werkblad, een los papiertje (voor de antwoorden), een pen en een rekenmachine
2. Zet een stopwatch aan vanaf het moment dat ze beginnen.
3. Laat ze de opdrachten maken
4. Na voltooien mogen ze ook de andere werkbladen doorkijken en verder MOTIONz ontdekken

Deel 5: SUS survey (geef ze de survey om in te vullen) (5 min)

Geef ze de SUS survey om in te vullen. De extra uitleg indien nodig kan ook worden gebruikt tijdens dit gedeelte als de participanten nog vragen hebben over wat ze in moeten vullen.

Deel 6: UEQ survey (geef ze de survey om in te vullen) (5 min)

Geef ze de UEQ survey om in te vullen.

Deel 7: Semi-Structured Interview (zet de audio recording aan) (7 min)

Stel de onderstaande vragen aan de participanten.

1. Kun je je algemene ervaring met het product beschrijven?
2. Welke aspecten van het product vond je met name nuttig of waardevol in de context van educatie?
3. Waren er specifieke functies of mogelijkheden die je opvielen? Zo ja, waarom?
4. Kwam je uitdagingen of moeilijkheden tegen bij het gebruik van het product? Zo ja, kun je deze toelichten?
5. Hoe zou je het product beschrijven wat betreft gebruiksgemak en intuïtiviteit?

6. Hoe verhoudt een lesmateriaal als dit product zich tot lesmaterialen die je normaal of in het verleden hebt gebruikt?
7. Denk je dat dit product geschikt is voor het onderwijs dat jullie aanbieden of willen aanbieden?
8. Denk je dat leerlingen dit product vaker zouden willen gebruiken?
9. Wat denk je dat de impact van dit product is op de leerervaring van leerlingen?
    a. Denk je dat die beter, hetzelfde of slechter zou zijn?
10. Kun je specifieke scenario's of contexten bedenken waarin het product het meest nuttig of waardevol zou zijn voor leerlingen?
11. Denk je dat dit product beter de leerbehoeftes van leerlingen kan vervullen dan de huidige lesmaterialen?
    a. Of denk je dat het eerder een goede aanvulling is?
12. Zou jij dit product zelf gebruiken in je lessen?
    a. Of wat zou je nodig hebben voordat je het zou gebruiken?

13. Kun je suggesties of ideeën geven om de bruikbaarheid, gebruikerservaring of iets anders van het product te verbeteren?
14. Is er nog iets anders dat je wilt delen over je ervaring met het product of nog een suggestie die je zou willen meegeven?

Deel 7: Vragen voor mij (lees dit voor)

Heb je eventueel nog vragen voor mij of andere dingen die je nog zou willen delen?

Deel 8: Bedanken & Afronding

-

Appendix F – System Usability Scale

The System Usability Scale (SUS) was used post-task during the sessions. The original version was translated into Dutch which resulted in the questionnaire below. An extra set of explanations was created (next page) to help participants with understanding the question as it was intended.

Reference: Brooke, J. (1986). System usability scale (SUS): a quick-and-dirty method of system evaluation user information. Reading, UK: Digital equipment co ltd, 43, 1-7.

1) Ik denk dat ik dit product vaker zou willen gebruiken.

Volledig mee oneens	Mee oneens	Neutraal	Mee eens	Volledig mee eens

2) Ik vond het product onnodig complex.

Volledig mee oneens	Mee oneens	Neutraal	Mee eens	Volledig mee eens

3) **Ik vond het product gemakkelijk te gebruiken**.

Volledig mee oneens	Mee oneens	Neutraal	Mee eens	Volledig mee eens

4) Ik denk dat ik de ondersteuning van een technisch persoon nodig zou hebben om dit product te kunnen gebruiken.

Volledig mee oneens	Mee oneens	Neutraal	Mee eens	Volledig mee eens

5) Ik vond de verschillende functies in dit product goed geïntegreerd.

Volledig mee oneens	Mee oneens	Neutraal	Mee eens	Volledig mee eens

6) Ik vond dat er te veel inconsistentie was in dit product.

Volledig mee oneens	Mee oneens	Neutraal	Mee eens	Volledig mee eens

7) Ik kan me voorstellen dat de meeste mensen dit product heel snel zouden leren gebruiken.

Volledig mee oneens	Mee oneens	Neutraal	Mee eens	Volledig mee eens

8) Ik vond het product erg omslachtig om te gebruiken.

Volledig mee oneens	Mee oneens	Neutraal	Mee eens	Volledig mee eens

9) Ik voelde me erg zelfverzekerd bij het gebruik van het product.

Volledig mee oneens	Mee oneens	Neutraal	Mee eens	Volledig mee eens

10) Ik moest veel dingen leren voordat ik aan de slag kon met dit product.

Volledig mee oneens	Mee oneens	Neutraal	Mee eens	Volledig mee eens

Extra uitleg (indien nodig)

1. Ik zou dit product vaker in mijn onderwijs willen gebruiken
2. Ik vind het product te moeilijk te begrijpen zonder dat ik daar een reden voor zie
3. –
4. –
5. Ik vind dat alle onderdelen en doelen van het product goed zijn samengevoegd in dit ontwerp
6. Ik vind dat sommige onderdelen of doelen veel verschillen van elkaar waardoor er een verschil ontstaat van hoe goed het werkt, eruit ziet, etc.
7. Ik denk dat mensen dit makkelijk kunnen leren te gebruiken
8. Ik vind het product onhandig, ingewikkeld of tijdrovend is in gebruik
9. –
10. Ik moest veel voorkennis nodig hebben om dit product te begrijpen en gebruiken

Appendix G – User Experience Questionnaire

A User Experience Questionnaire (UEQ) was used to gain further insight into the user experience of MOTIONz. The Dutch UEQ was used which can be found on the pages below. Both the item-list and analysis tools used to analyze the results are from the original authors/creators, see reference below.

Reference: Laugwitz, B., Schrepp, M. & Held, T. (2008). Construction and evaluation of a user experience questionnaire. In: Holzinger, A. (Ed.): USAB 2008, LNCS 5298, pp. 63-76.

Website: https://www.ueq-online.org/ (holds links to all files and tools for the UEQ)

Maak dan nu uw evaluatie.

Voor de beoordeling van het product, vragen we u de onderstaande vragenlijst in te vullen. De vragenlijst bestaat uit twee tegengestelde eigenschappen die van toepassing zijn op het product. De rondjes staan voor verschillende gradaties. U kunt uw beoordeling geven door het rondje, die het meest uw indruk weerspiegelt, aan te vinken.

Voorbeeld:

aantrekkelijk	○	⊗	○	○	○	○	○ onaantrekkelijk

Dit antwoord zou betekenen dat u het product beoordeelt als meer aantrekkelijk dan onaantrekkelijk.

Graag uw eerst ingeving invullen. Wacht niet te lang met invullen om te voorkomen dat u gaat twijfelen over uw eerste ingeving.

Soms bent u misschien niet helemaal zeker van uw antwoord of u vindt de eigenschap niet volledig van toepassing, kruis dan toch een rondje aan.

Het is uw mening die telt. Let op: er is geen goed of fout antwoord!

Gelieve beoordeel het product nu door het aanvinken van een rondje per regel.

	1	2	3	4	5	6	7		
onplezierig	○	○	○	○	○	○	○	plezierig	1
onbegrijpelijk	○	○	○	○	○	○	○	begrijpelijk	2
creatief	○	○	○	○	○	○	○	saai	3
makkelijk te leren	○	○	○	○	○	○	○	moeilijk te leren	4
waardevol	○	○	○	○	○	○	○	inferieur	5
vervelend	○	○	○	○	○	○	○	spannend	6
oninteressant	○	○	○	○	○	○	○	interessant	7
onvoorspelbaar	○	○	○	○	○	○	○	voorspelbaar	8
snel	○	○	○	○	○	○	○	langzaam	9
origineel	○	○	○	○	○	○	○	conventioneel	10
belemmerend	○	○	○	○	○	○	○	ondersteunend	11
goed	○	○	○	○	○	○	○	slecht	12
complex	○	○	○	○	○	○	○	eenvoudig	13
afstotend	○	○	○	○	○	○	○	aantrekkelijk	14
gebruikelijk	○	○	○	○	○	○	○	nieuw	15
onaangenaam	○	○	○	○	○	○	○	aangenaam	16
vertrouwd	○	○	○	○	○	○	○	niet vertrouwd	17
motiverend	○	○	○	○	○	○	○	demotiverend	18
volgens verwachtingen	○	○	○	○	○	○	○	niet volgens verwachtingen	19
inefficiënt	○	○	○	○	○	○	○	efficiënt	20
overzichtelijk	○	○	○	○	○	○	○	verwarrend	21
onpraktisch	○	○	○	○	○	○	○	praktisch	22
ordelijk	○	○	○	○	○	○	○	rommelig	23
aantrekkelijk	○	○	○	○	○	○	○	onaantrekkelijk	24
aardig	○	○	○	○	○	○	○	onaardig	25
conservatief	○	○	○	○	○	○	○	innovatief	26

Appendix H – Semi-Structured Interview Question List

A list of questions was created to further elaborate on the usability and user experience of the project as well as to assess its suitability for education. The list elaborates on several of the quantitative questions asked in the SUS and UEQ questionnaires but rather aims to open up a conversation about them to gain more in-depth insights. (All questions are in Dutch)

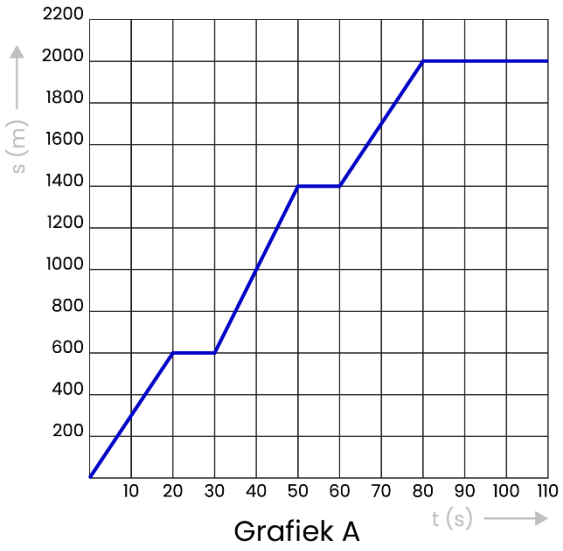
15. Kun je je algemene ervaring met het product beschrijven?
16. Welke aspecten van het product vond je met name nuttig of waardevol in de context van educatie?
17. Waren er specifieke functies of mogelijkheden die je opvielen? Zo ja, waarom?
18. Kwam je uitdagingen of moeilijkheden tegen bij het gebruik van het product? Zo ja, kun je deze toelichten?
19. Hoe zou je het product beschrijven wat betreft gebruiksgemak en intuïtiviteit?
20. Hoe verhoudt een lesmateriaal als dit product zich tot lesmaterialen die je normaal of in het verleden hebt gebruikt?
21. Denk je dat dit product geschikt is voor het onderwijs dat jullie aanbieden of willen aanbieden?
22. Denk je dat leerlingen dit product vaker zouden willen gebruiken?
23. Wat denk je dat de impact van dit product is op de leerervaring van leerlingen?
    a. Denk je dat die beter, hetzelfde of slechter zou zijn?
24. Kun je specifieke scenario's of contexten bedenken waarin het product het meest nuttig of waardevol zou zijn voor leerlingen?
25. Denk je dat dit product beter de leerbehoeftes van leerlingen kan vervullen dan de huidige lesmaterialen?
    a. Of denk je dat het eerder een goede aanvulling is?
26. Zou jij dit product zelf gebruiken in je lessen?
    a. Of wat zou je nodig hebben voordat je het zou gebruiken?
27. Kun je suggesties of ideeën geven om de bruikbaarheid, gebruikerservaring of iets anders van het product te verbeteren?
28. Is er nog iets anders dat je wilt delen over je ervaring met het product of nog een suggestie die je zou willen meegeven?

Appendix I – Final Worksheets

DE BLAUWE TRUCK

Alex is aan het verhuizen en gebruikt de truck van haar vader om al haar spullen te verplaatsen naar het nieuwe huis.

Grafiek A is een versimpelde afstand-tijd diagram van een ritje van het oude naar het nieuwe huis dat ze aflegt.



Grafiek A

1. Leg uit hoe je aan de grafiek kan zien dat ze haar spullen aan het uitladen is in haar nieuwe huis.

2. Meet een aantal keer de snelheid van de truck.
   (beweeg de truck over de weg totdat je 3 verschillende snelheidsmetingen hebt verzameld)

   A. Bereken met de snelheidsmetingen de gemiddelde snelheid van de truck.

   B. Komt de gemiddelde snelheid overeen met de gemiddelde snelheid in grafiek A?
      (leg uit welke stappen je hebt genomen om dit te bepalen)

3. Alex's partner heeft ook een truck van iemand geleent die toevallig heel veel lijkt op de truck van Alex. Haar partner rijd alleen veel harder dan Alex, meet en bereken de topsnelheid die truck kan bereiken.

   A. De topsnelheid van de truck is wel veel hoger dan de maximum toegestane snelheid, dus Alex's partner rijd iets langzamer. Haar partner komt 20 seconden eerder aan, wat is de gemiddelde snelheid van de partner?
      (gebruik de grafiek om de afstand te bepalen en daarmee de gemiddelde snelheid)

MOTION

DE GROENE VRACHTWAGEN

Vrachtwagenchaffeur Finn rijd elke dag van Eindhoven naar Frankfurt om groente en fruit op te halen. Na het laden, rijdt hij weer terug naar Eindhoven.

Figuur 1: Finn's Vrachtwagen

1. Meet en bereken de gemiddelde snelheid van zijn vrachtwagen.
   (meet minimaal 3 keer zijn snelheid en bereken daarna de gemiddelde snelheid)

2. Op de heenweg legt Finn ongeveer 350 kilometer af.

   A. Hoelang doet hij erover met zijn gemiddelde snelheid om in Frankfurt te komen?
      (ga ervanuit dat hij de gehele weg zijn gemiddelde snelheid rijdt en geef antwoord in minuten)

   B. Finn moet twee verplichte pauzes van 30 minuten houden op de heen én de terugweg. Met de pauzes erbij, hoelang doet hij in totaal over zijn reis?

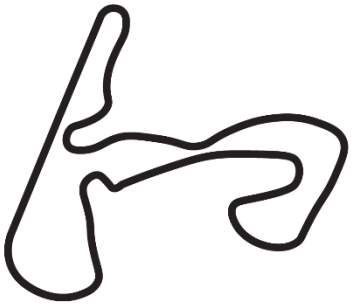
   C. Maak van zijn gehele reis een s,t-diagram, waarbij het laden in Frankfurt 1 uur duurt.

MOTION

DE RODE RACEAUTO

Devon is al jaren een fan van race auto's en mag nu eindelijk een keer een ritje maken op het circuit van Zandvoort.

Figuur 1 is een plaatje van het circuit en de baan die word afgelegd tijdens een rondje.



Figuur 1:
Circuit van Zandvoort

1. Meet de topsnelheid die de auto kan bereiken.
   (meet minimaal 3 keer om de topsnelheid te vinden)

2. Als 1 rondje rijden 66 seconden duurt, hoeveel afstand legt Devon in de raceauto af op topsnelheid?
   (neem aan dat de auto tijdens het hele rondje op topsnelheid rijd)

3. Tussendoor moet Devon ook even stoppen in de pitstraat om de banden te laten wisselen.
   A. Hier moet de auto zo langzaam mogelijk rijden voor de veiligheid van alle mensen om de auto heen, wat is de laagst mogelijke snelheid die de auto kan rijden?
      (meet minimaal 3x de snelheid van de auto voordat je antwoord geeft)

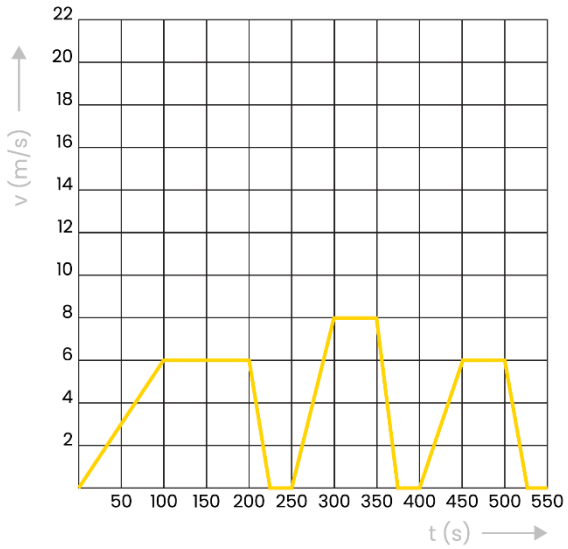
   B. De pitstraat is 100m lang en het wisselen van de banden duurt 5 seconden. Hoelang doet Devon in totaal over door de pitstraat rijden met de laagst mogelijke snelheid?
      (tijdens het wisselen van de banden is Devon's snelheid 0 km/h, ga er vanuit dat de rest van de tijd de auto in de pitstraat op de laagst mogelijke snelheid rijd)

MOTION

HET GELE POSTBUSJE

Malou is pakketbezorger en rijd in haar postbusje door de Eindhovense wijken om alles netjes af te leveren.

Een vriend van haar, Rafi, heeft een v,t-diagram gemaakt van haar route in de wijk Gestel, zie grafiek A, waarbij ze drie pakketjes heeft bezorgd.



Grafiek A: Rafi's Diagram

1. Meet een aantal keer de snelheid van het postbusje.
   (beweeg het postbusje over de weg totdat je 3 verschillende snelheidsmetingen hebt verzameld)

   A. Bereken met de snelheidsmetingen de gemiddelde snelheid van het postbusje.

2. Ga na of de grafiek die Rafi heeft gemaakt wel de juiste snelheden heeft.
   (doe dit door Vgem uit vraag 1 te vergelijken met Vgem in de grafiek)

3. Hoeveel afstand legt Malou af tijdens haar rondje in Gestel volgens Rafi's Diagram?

4. Malou rijd elke ochtend langs 5 verschillende wijken. Als ze van wijk naar wijk rijd mag ze veel harder rijden. Wat is de topsnelheid die Malou dan zou kunnen bereiken?

   A. Malou doet ongeveer 5 minuten erover om van wijk naar wijk te rijden, hoeveel kilometer legt ze dan op een dag af als ze op topsnelheid zou rijden?
      (ga ervan uit dat ze begint vanaf het postcentrum en nog naar de eerste wijk moet rijden, tel die wijk als wijk 1)

MOTION

Appendix J – Original Research Framing & Set-Up

How do embodied tangibles influence the understanding of physics phenomena in secondary STEM education?

Why?

- Teachers express a need for more practice-based learning
    - Being able to practice the theory/concepts in real-life
    - Experimenting with concepts to being able to understand it better
    - Being able to relate theory to the real world around them (the students)
    - Being able to diversify teaching
        - They are currently not able to do that as not all topics are able to be 'translated' into experiments
    - There is room for experimental learning but … (see next point)
    - They feel there would be lots of benefits for more practice-based learning for the students
        - Students motivation, engagement and enjoyment can increase
        - But also their cognitive abilities in the subject
- Teachers have a lack of time/creativity creating these things on their own
    - There is a need for something to be implemented in the current curriculum
    - There is a want for extra tools to be used in class but without having to put too much time in it themselves (the teachers)
    - It can be hard to think of new creative ways of teaching with a lack of time
- STEM education in the Netherlands _____
    - Does not have a lot of experimental or practice-based learning
    - In the lower grades contains a lot of repetition to 'learn' concepts & theory
    - Does have the flexibility to play around with topics, concepts and theory in class
    - Does mostly consist of Physics & Math
- Physics is currently
    - Mostly focused on teaching theory and concepts
        - Rather than experimenting with them or playing with them
    - Mostly completing exercises from the books
    - Being taught in a very traditional way
        - Instruction for the class (with a powerpoint to support), then making exercises
- Tangibles can provide the medium of facilitating theory to practice
    - Also can provide several other benefits:
        - Engagement
        - Motivation
        - Enjoyment
        - Cognitive abilities
    - It is also able to represent bigger things on a smaller scale
        - Like vehicles (cars, trucks, airplanes and more)
        - But they can also be representations of certain abstract or intangible concepts

(potential) benefits of doing this study

- Improving current educational practices through design
    - Without disrupting the curriculum
- Being able to bring real world concepts to the classroom
    - And guide designers on how to do this
- Showing there is a benefit to practicing concepts students are taught in experimental sessions/lessons
- Being able to share how to translate theory into practicable concepts
- Showing the (potential) educational impact of experimental learning

How? (potential options)

- Self-reports
- Self-estimates
- Worksheet results
- Questionnaire before and after activity
- Semi-structured interview

Related Work

These are some of the papers I found that relate to my work in some way. I have included them here but if you have more suggestions, let me know!

Tangibles in Educational Contexts

- Xie, L., Antle, A. N., & Motamedi, N. (2008, February). Are tangibles more fun? Comparing children's enjoyment and engagement using physical, graphical and tangible user interfaces. In *Proceedings of the 2nd international conference on Tangible and embedded interaction* (pp. 191-198).
- Zaman, B., Vanden Abeele, V., Markopoulos, P., & Marshall, P. (2012). the evolving field of tangible interaction for children: the challenge of empirical validation. *Personal and Ubiquitous Computing*, *16*, 367-378.
- Marshall, P. (2007, February). Do tangible interfaces enhance learning?. In *Proceedings of the 1st international conference on Tangible and embedded interaction* (pp. 163-170).
- O'Malley, C., & Fraser, D. S. (2004). Literature review in learning with tangible technologies.
- Antle, A. N., & Wise, A. F. (2013). Getting down to details: Using theories of cognition and learning to inform tangible user interface design. *Interacting with Computers*, *25*(1), 1-20.
- Zuckerman, O., Arida, S., & Resnick, M. (2005, April). Extending tangible interfaces for education: digital montessori-inspired manipulatives. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 859-868).

STEM Education

- August, S. E., Neyer, A., Murphy, D. B., & Thames, R. Q. (2011, June). Engaging students in STEM education through a virtual learning lab. In *2011 ASEE Annual Conference & Exposition* (pp. 22-573).
- Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., ... & Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, *3*(1), 2.
- Brown, J. (2012). The current status of STEM education research. *Journal of STEM Education: Innovations and Research*, *13*(5).

(Measuring) Understanding/Cognitive Abilities

- Self-reporting abilities before and after the activity in combination with the answers from the practice sheet (which is completed during the exercise)
- Rasch Model
    - Still unsure if this possible as it reports on the correlation between difficulty and performance and I am not so focused on difficulty levels, but thought it might be good to still include it in the search
- Woodcock/Johnson test of Cognitive Abilities
    - Have not been able to find a list of them so unsure if they are really suitable but several papers recommended them
        - They also named these to be similar: Stanford-Binet, Wechsler Intelligence
- Related papers I found:
    - Widhiarso, W. (2014). Relationship between cognitive ability and accurate self-reporting. *Journal of Educational Sciences and Psychology*, *14*(2), 85-95.
    - Greene, B. A. (2015). Measuring cognitive engagement with self-report scales: Reflections from over 20 years of research. *Educational Psychologist*, *50*(1), 14-30.
    - Crooks, N. M., & Alibali, M. W. (2014). Defining and measuring conceptual knowledge in mathematics. *Developmental review*, *34*(4), 344-377.
    - Sands, D., Parker, M., Hedgeland, H., Jordan, S., & Galloway, R. (2018). Using concept inventories to measure understanding. *Higher Education Pedagogies*, *3*(1), 173-182.
    - Read, J. C., & MacFarlane, S. (2006, June). Using the fun toolkit and other survey methods to gather opinions in child computer interaction. In *Proceedings of the 2006 conference on Interaction design and children* (pp. 81-88).

I think I will use a mixed method approach as lots of the tools out there are quantitative but I would like to use qualitative data to be able to explain it and inform about the potential of such a design.