# Design of Interactive STACK Exercises Using JSXGraph for Online Course: Exploring Strategies for Supporting Students with Mathematical Challenges

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Abstract:     The integration of technology into education has changed the way students learn and utilise course materials in online courses. However, the effectiveness of online courses greatly depends on the quality of learning materials, the ability to provide feedback and interactivity. With regard to mathematical exercises, the issue of designing interactive tasks has not yet been adequately addressed. This article presents a model to support the design of automatic interactive exercises using the Moodle STACK plugin and the JavaScript library JSXGraph, with special attention paid to providing immediate feedback and supporting students with mathematical challenges. We also delve into the technical aspects of the design of interactive exercises to highlight the opportunities and challenges that open-source tools bring to the creation of digital tasks. We argue that with careful exercise design and attention to specific technical considerations, interactive STACK exercises created with JSXGraph can particularly enhance students' understanding of conceptual aspects in the mathematical sciences. A specific example exercise is given, and its design is discussed. In conclusion, this article extensively discusses important factors to consider in the design of interactive exercises and examines rarely addressed issues in the design of automatic digital tasks, such as accessibility, pedagogical soundness, expanding the possibilities of immediate hints, dynamic guiding of students, feedback, and students with mathematical challenges.

## 1 INTRODUCTION

Continuous learning is more and more popular nowadays. In the changing world of work, updating one's own competence is vital. This is especially important for the unemployed and people who did not finish school. The prospects for people without a degree are poor, which may affect their self-esteem and increase exclusion. In education, mathematical skills are often emphasised from the application phase. If a person has not studied for a long time or if their schooling was interrupted due to poor mathematical skills, it will be necessary for them to repeat the basics. The educational background of the disadvantaged is usually lower, suggesting that traditional education may not have been the best

option for them. This paper introduces an online course specifically aimed at helping the disadvantaged improve their mathematical skills.

Learning in self-paced online course requires motivation and self-direction. If students do not have self-efficacy, meaning that they do not believe in their own ability to learn, self-paced online courses may not be the best option. Even with good self-efficacy, students require a good reason (motivation) and commitment to do well on self-paced online courses. And still life may throw a spanner into the wheel and make it difficult to study. This paper studies methods of improving self-efficacy and commitment by giving encouraging feedback interactively during problem solving, not only after answers are submitted.

Dropping out of online courses is common and the reasons for this have been extensively studied (Bawa,

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2016; Onah et al., 2014; Shaikh & Asif, 2022). Since independent online courses lack teacher contact, the structure of the course is crucial. A course which is poorly implemented technically, and pedagogically confusing will not motivate students to complete it. If students receive feedback on their competence only at the end, they do not have the opportunity to focus on the topics they understand poorly. The effectiveness of online courses greatly depends on the quality of learning materials, the ability to provide feedback and interactivity. It has been argued that the major limitation of online courses is the lack of rich, well supported activities as a framework for learning by doing (Koedinger et al., 2015).

E-learning environments such as Moodle are being used to host and deliver online activities and assessments. A range of assessments and activity types are available, from filling in the blanks to multiple choice questions. The Moodle platform has specific tools to enwiden the range of interactive activities in mathematical sciences, namely the e-assessment system STACK and the JavaScript library JSXGraph for dynamic geometry.

This paper presents a model for designing interactive exercises using STACK (*STACK Documentation*, 2024) and JSXGraph (*JSXGraph Documentation*, 2024), with a focus on providing immediate feedback and accommodating students with mathematical challenges. Technical aspects of the design of interactive exercises are discussed. We highlight the opportunities and challenges that open-source tools bring to the creation of digital tasks.

The paper argues that interactive STACK exercises created with JSXGraph can enhance students' understanding of conceptual aspects in the mathematical sciences. The design of interactive exercises should consider factors such as accessibility, expanding the possibilities of immediate hints, feedback, dynamic guiding of students, a learner-centred approach and students with mathematical challenges.

## 2 TECHNICAL ASPECTS OF INTERACTIVE EXERCISE DESIGN

STACK is a prominent open-source e-assessment system which operate within the Moodle and integrates effectively with other platforms. Utilising an open-source Computer Algebraic System (CAS) called Maxima (*Maxima Documentation*, 2024), STACK tasks are programmed mainly using Maxima

syntax. Furthermore, STACK permits specific functions which are absent in Maxima but are crucial for the generation of STACK tasks. Responses to STACK tasks can use mathematical formats such as polynomials, matrices, integers and floating-point numbers. Personalised versions of tasks are enabled through randomisation of initial values, ensuring unique renditions for each student. Traditional STACK tasks, lacking the interactive interface, commonly require answers to be typed into designated answer fields. More advanced interactivity, such as mouse interactions with geometrical shapes, text objects or equations, can be introduced via JSXGraph, a dynamic geometry software that has been integrated into STACK.

The versatility of JSXGraph permits the creation of diverse content by capitalising on JavaScript's adaptability to construct interactive components, limited only by the task creator's programming expertise. The visualisation capacities of JSXGraph offer numerous possibilities in digital task design, such as visual prompts and responses.

In interactive tasks, hidden answer fields may contain diverse data types, such as the coordinates of interactively manipulatable objects, lists or Boolean values. One fundamental principle in the coding of interactive tasks is that the final state of JSXGraph should be restored, meaning that the position of objects as set by the student before checking the answer can be restored and the final state shown rather than the initial state. STACK provides object binding functions tailored to JSXGraph but in more complex situations storing the JSXGraph state as a JSON string is a feasible method.

The realm of digital tasks offers both opportunities and challenges, particularly concerning the completion of STACK tasks. Amour (2023) highlights the fact that developing proficient STACK tasks is time-consuming and incorporating interactivity with JSXGraph demands even more time. Nonetheless, that meticulously designed digital resources will be valuable for next several years is undeniable. Mastery of coding skills is crucial, including an in-depth understanding of Maxima syntax and the commands and functions utilised in STACK. Equally important is a thorough grasp of the requirements for constructing a STACK task within the Moodle environment. Moreover, integrating interactive elements requires expertise in JSXGraph. Proficiency in both the JSXGraph library and its documentation, along with a wider comprehension of JavaScript, is essential to incorporate interactive elements into STACK tasks. The primary constraint when developing interactive tasks is the coder's

programming abilities. Although artificial intelligence can aid in JSXGraph task creation, full integration of interactive elements within STACK tasks is not yet possible as JSXGraph works in a sandbox within STACK, which requires special knowledge.

The benefits arising from interactive tasks can permeate all levels of education. This paper seeks to demonstrate the effectiveness of these tasks in enhancing fundamental mathematical skills and solidifying foundational mathematical concepts. Although these aspects may not be the primary focus in higher education institutions where it is assumed students possess adequate competencies in mathematical sciences, the decline in mathematical skills has been steep in recent years. Consequently, developing supportive measures with the aim of strengthening basic mathematical skills to facilitate successful higher education pursuits is now urgent.

# 3 MODEL FOR DESIGNING INTERACTIVE EXERCISES

Several particular aspects must be considered in the design of the assessment and learning environments for online courses. Promotion of self-directed learning skills, authenticity of exercises and well-timed, appropriate feedback form the characteristics of a powerful online learning model (Hurme et al., 2023). Thus, concentrating on mindset and self-directive learning skills may help disadvantaged students complete a course. Shaikh and Asif (2022) also remark that motivational incentives such as financial outcomes may help with persistence.

Rasila et al. (2015) outlines how the presentation of mathematics plays a pivotal role in the construction of an agreeable user experience. The mathematical content of online courses needs to be comprehensible without a teacher's assistance, and the interaction between the student and the computer should be as seamless as possible. Furthermore, certain issues with materials and systems may subsequently be identified indirectly through students' exercise response data as gathered by the e-learning environment. In every instance, user feedback and ensuing revisions of both the e-learning platform and study materials are necessary to enhance the user experience.

Koedinger et al. (2015) showed that engaging in interactive activities during online courses yields more significant improvements in study outcomes compared to simply watching videos or reading theoretical material. Interactive activities foster active learning which is more effective than passive

knowledge acquisition, and the learning-by-doing method seems to be a reasonable foundation for the design of an online course.

Paiva et al. (2015) argues that interactive learning modules, including interactive multimedia books, online quizzes and tutorial videos, create an effective online learning environment for mathematics in higher education. Students with initially lower basic maths skills showed significant improvement after such modules, highlighting the potential of the interactive approach to bridge learning gaps in mathematics. The study provided evidence that interactivity could be an effective tool for enhancing learning outcomes. Velichová (2021) sums up that learning by doing enhances learners' motivation, enthusiasm, interest, attitude towards the entire learning process and desire to acquire new knowledge.

Modern e-learning environments permit the creation of more diverse mathematical tasks for STEM courses compared to the era of textbook-sourced tasks (Rasila et al., 2015). Traditional digital tasks often resembled textbook problems and were crafted similarly. However, dynamic geometry software introducef an innovative dimension to interactive tasks (Gerhäuser et al., 2011), and Bach et al. (2021) confirmed that dynamic geometry facilitates the development of challenging visual conceptual tasks while enabling novel advancements thanks to JavaScript's versatility.

Interactive tasks in higher education are increasingly prevalent; however, effective design frameworks remain scarce. It is crucial to acknowledge that open-source tools can generate impactful interactive tasks, and accessibility must be considered to ensure compatibility with users' diverse needs. Interactive tasks should adopt a learner-centred approach, simplifying phenomena so that interactivity aids comprehension of the underlying principles. The technical design should not be overly complex, and brief instructions should suffice in order for task objectives to be understood.

## 3.1 Inclusive Design Approach

An inclusive design approach is essential when crafting interactive tasks. This may involve dynamic warning messages, guiding messages or hints to create an engaging and motivating experience for students. Moreover, usability must be addressed, ensuring that interactive functions fulfil their intended purpose efficiently and intuitively. The model of Porras et al. (2023) for designing interactive tasks to enhance the basic conceptualisation and skills in mathematics draws on the work of Bloom (1984)

and Pelkola (2018). This model emphasises the power of automated assessment and feedback to provide the seeds to support a growth in self-regulation and learning for mastery of mathematical skills. It is crucial to design interactive tasks and assessment in a learner-centred way, thereby promoting active student participation in a powerful learning environment. Brown (2023) expanding on the thoughts of Winne (1982), reasons that if the learning environment is not inclusive there is a risk that students who are less able to mediate or self-regulate their learning will face barriers. Therefore, self-regulation is a key characteristic in models of powerful e-learning environments.

## 3.2 Feedback Is a Key Component of the Learning Process

Feedback, whether associated with guidance or assessment of activities, should be seen as an act which will affect students' future performance. Coherent feedback requires explanations with three informative components: why something is incorrect, how the error should be construed and what may help solve the problem (Brown, 2023; Shute, 2008; Torrance, 2012). The third component of coherent feedback involves providing the student with ideas to strengthen their learning and information on which areas are now under control, giving a positive impact to learning.

Malecka et al. (2022) described some elements which can help students better understand the function of assessment and its role in the learning process: a positive attitude towards feedback, improving feedback literacy and constructing an understanding of feedback cycles. This is challenging in fully online courses, but it is necessary to put into practice when giving feedback on activities and exams.

Assessment and feedback related to standard exercises and activities will strongly influence students' capacity to learn. The idea is to reveal and address issues related to thinking, concepts, procedures and modelling. Traditionally, when teachers carry out assessments they interpret students' outputs i.e. the representations of their learning outcomes. Teachers use their professional judgment based on what they have read. In blended learning environments, although some automatic evaluation is used in e-learning environments, teachers have the possibility of explaining their assessment policies at some level. On massive open online courses (MOOC) this is not possible, and poorly designed tasks increase difficulty in e-learning environments, therefore a new form of assessment is required. System output after an assessment should allow students to better understand their learning progress and the outcomes of

the activities or exams in question. There is a quest for assessment to be both personal and at the same time general, equitable and fair, to include clear feedback, and to fulfil classical evaluation criteria. In order to ensure this, the central role of feedback and guidance need to be understood and described accurately. A conceptual re-thinking of the role of assessment in e-learning environments is required to meet the expectations of all stakeholders (namely students and educators) in the learning process so that learning outcomes can be evaluated in a coherent way.

### 3.2.1 Feedback types

Feedback and guidance can be classified in terms of the desired level of the student's action:

- Instant and formative (right or wrong) (IF)
- Informative, process-oriented (address the gap in knowledge) (IP)
- Informative, concept-oriented or subject-oriented (IC)
- Selective, student can choose the amount and type of feedback (S)
- Facilitative, meaning informative and selective (FA)
- Immediate (I) or delayed (D)

An example of instant and informative (IF) feedback can be seen in an activity which is scored directly as either right or wrong. When solving. first or second order polynomial equations, for example, the process is clearly traceable, and any gaps are addressable. This clarifies which feedback type (IC or IP) is needed. Selective feedback is needed to define the content of the facilitative form of assessment (FA). Selectivity authorises the learner to decide the level of support they desire. The most intrinsic new approach is the facilitative form of assessment and guidance (FA). In this the student's role is the true focus. Immediate feedback (I) is effective particularly when learners lack some basic knowledge which is essential for addressing questions or resolving problems and prevents learners from grappling incessantly without any prospect of success. Therefore, immediate feedback is applied in this context even though delayed feedback (D) has been shown to reduce cognitive load and engender deeper cognitive processing, as this applies only in cases where students have basic knowledge of the matter at hand. Trenholm et al. (2015) suggest that immediate feedback promotes procedural learning, while delayed feedback supports conceptual learning. Optimal feedback focuses on learning tasks and developing an understanding of the task's underlying concepts. As mentioned above, in the context of a

complete lack of basic mathematical skills, delayed
feedback is not a feasible option.

### 3.2.2 The Hint Matrix as a Tool for Facilitative Feedback

An effective method for offering immediate support
to students without requiring a response is to employ
a hint matrix (refer to Figure 1). Hint matrices can be
incorporated into any STACK task using JSXGraph,
with the task designer determining when it is
appropriate for students to receive hints, potentially
from the beginning of the task. The main principle of
the hint matrix is that as the black dot is dragged
horizontally theoretical hints pertinent to the task
appear; concurrently, as the black dot is dragged
vertically, practical hints relevant to solving the task
appear. The students themselves are able to control the
number and quality of hints by dragging the black dot.

It is crucial to stress that students should
endeavour to progress independently in a task with
minimal hints. This is necessary in order to minimise
the chances of a student quickly moving the black dot
to the upper right corner of the hint matrix, revealing
all possible hints. Although this cannot be directly
prevented in an online course, efforts should be made
to inform students that solving tasks independently is
crucial to their learning and understanding, and
merely accessing all hints without personal reflection
is not recommended.

Various tools for offering hints can be devised to
enhance students' reflective and cognitive processes.
While not all tasks necessitate hints, in certain cases,
it may prove advantageous for students to begin tasks
with the assistance of hints, particularly in online
courses without direct teacher-student interaction.
The hint matrix exemplifies how students can actively
engage in constructing their understanding and
consider what level of support will best foster
development of problem-solving competency.

Open-source digital tools can be used to design
and implement various task frameworks for a range
of students and learners. Additionally, there are
diverse ways to provide hints. Owing to security
concerns surrounding the unrestricted incorporation
of JavaScript into STACK, it is likely that its
integration into STACK tasks will be restricted in the
foreseeable future. This will constrain the inclusion
of external content such as audio or video links within
STACK tasks. The multitude of possibilities presents
challenges regarding time management and the
identification of pedagogically efficacious methods,
thus necessitating a focus on task clarity and
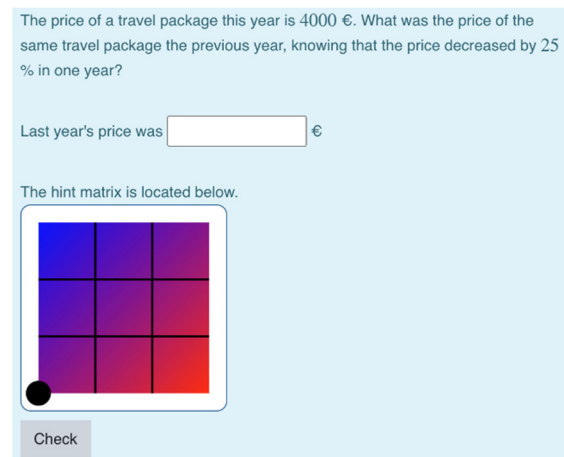coherence.



Figure 1: A hint matrix.

## 4 ENHANCING CONCEPTUAL UNDERSTANDING IN THE MATHEMATICAL SCIENCES

Rasila et al. (2015) posit that mathematical skills
comprise five interconnected components:
conceptual understanding, procedural fluency,
strategic competence, deductive abilities and interest.
They maintain that conceptual comprehension is the
critical element to render mathematical problem-
solving capabilities genuinely transferable.

Hooper and Jones (2023) recognise the challenges
in assessing conceptual understanding in online
courses, while procedural understanding can be
readily evaluated using automatic assessment
systems. Nonetheless, they demonstrated that
JSXGraph can address this issue, at least with simple
statistics. Students tend to perform better on
procedural tasks than conceptual ones, indicating an
ability to execute mechanical tasks without
necessarily grasping the underlying concepts (ibid).
This suggests that utilising interactive STACK tasks
may establish a foundation for improving students'
conceptual comprehension before they engage in
problem-solving activities which require an accurate
understanding of the subject matter.

Velichová (2021) contends that active student
participation facilitates improved understanding
through discovery and investigation rather than
memorisation of isolated facts. Conceptual
understanding entails not only identifying the correct
answer but also comprehending a step-by-step
solution. Interactive STACK tasks offer a potentially
infinite range of valid solution methods, which
requires students to grasp concepts and encourages

independent inquiry. This independent exploration facilitates development of in-depth comprehension of mathematical tasks.

Before the development of interactive interfaces for digital tasks, engaging with mathematical concepts was challenging due to a lack of suitable visual tools. The advent of interactive tasks presents an opportunity to diversify the learning environment within mathematical domains, fostering essential skills required in mathematics and the natural sciences. Consequently, it is reasonable to expect that interactive tasks will substantially enhance these foundational capabilities in the future.

Trenholm et al. (2015) highlight a discrepancy between studies on e-assessment systems: some demonstrate improved performance, while others indicate a focus on procedural learning. Certain students may adopt a trial-and-error approach, reaching the correct answers but misunderstanding concepts. This potential shortcoming of e-assignment systems could be mitigated by incorporating interactive tasks with graphical interfaces, as these inherently involve conceptual rather than procedural understanding.

Davies et al. (2022) noted that STACK tasks employed in undergraduate mathematics courses predominantly involved procedural tasks and lack purely conceptual tasks. Recognising this limitation of common STACK tasks, we will discuss one example of how conceptual STACK tasks can be developed using JSXGraph.

The exemplar task pertains to kinematics in physics (refer to Figure 2) and involves analysing the motion of a car with constant velocity. In the upper coordinate system, the automobile is represented at a distinct initial position with a specific constant velocity. Objects within this coordinate system remain unmovable; however, their positions and values are randomised.

Velichová (2021) asserts that employing non-linguistic representations during learning significantly enhances brain activity, thereby facilitating the formation of cognitive connections and promoting the acquisition of knowledge and deeper comprehension of fundamental principles and concepts.

In the lower coordinate system, students are required to drag black and blue points to accurately represent the real-world scenario depicted above. This exercise aims to illustrate the correlation between real-world situations and their corresponding graphical models. Within the coordinate system, green arrowheads indicate essential elements, and hovering over them reveals dynamic guidance regarding their significance.
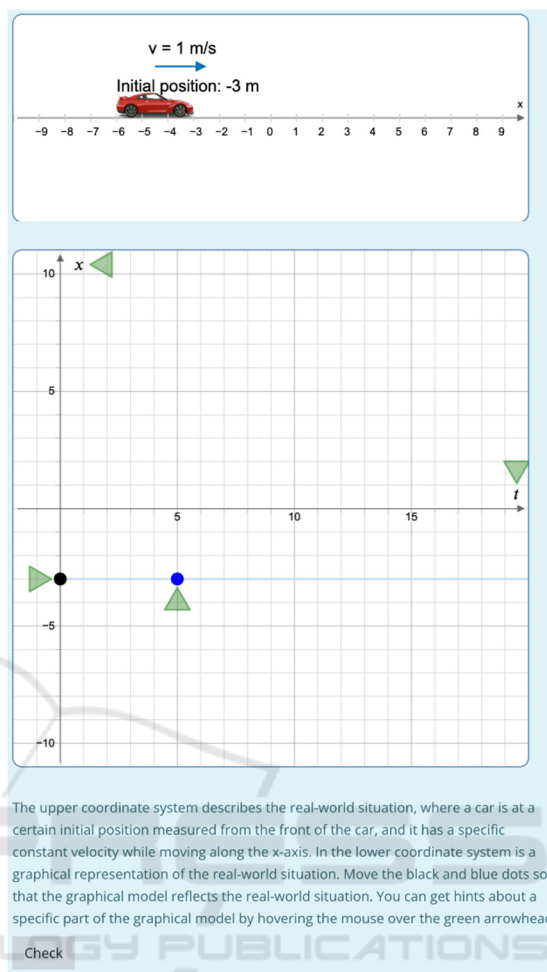


Figure 2: Car moving with constant velocity and the respective graphical model.

The incorporation of dynamic guidance proves particularly advantageous in assisting students with a weaker grasp of the subject to engage in problem-solving. Following Bloom's Learning for Mastery pedagogical method, subsequent tasks may replicate the original one but omit the green directive arrowheads. By incrementally increasing the difficulty of the similar tasks, mastery in each subject area can be attained. Interactive tasks offer several benefits, including effortless modification from simpler to more complex versions of similar tasks, which is hypothesised to maintain higher student engagement compared to solving nearly identical calculations.

This interactive approach reinforces students' understanding of how physical situations can be examined from multiple perspectives: constructing a graphical model based on real-world phenomena or interpreting data from a physical event. Schaathun

(2022) emphasises the importance of tasks being relevant to students' everyday lives and real-world phenomena.

Creating the upper coordinate system follows a relatively straightforward procedure. An image within this system was converted to Base64 format. Utilising Base64 ensures the image is included within the task, eliminating the need for external links. The initial position, vector length and numerical values are derived from random variables within STACK.

The design of the lower coordinate system employs scalability for different screen sizes and event listeners facilitated by JavaScript. By hovering over the green arrow tips, students can receive dynamic guidance relevant to that specific object. If this functionality is intended for touchscreens, additional event listeners need to be coded for finger and stylus events.

Both the black and blue points are movable. The black dot moves along the position axis as it denotes the initial position, while the blue point adjusts the physical slope given as velocity from the upper coordinate. When checking answers, restoration of the coordinate system's final state is achieved by storing the coordinates in hidden input fields as JSON strings. Additional hidden input fields store Boolean variables referring to the initial position and slope.

The potential impact of interactive STACK (2024) tasks crafted with JSXGraph (2024) is that students can attain foundational understanding before advancing to calculation-based tasks. Supported by dynamic guidance tools and self-guided learning mechanisms, interactive tasks offer diverse learning experiences. Interactive tasks require not only mechanical execution of solution steps but also comprehensive grasp of the underlying issues and recognising multiple correct solutions to a given problem, which can potentially enhance students' reasoning, problem-solving prowess, logical thinking and analytical capacities.

An inherent advantage of interactive tasks is that they allow students to independently investigate mathematical concepts. This exploratory approach enables students to discern mathematical patterns autonomously. Fundamentally, interactive tasks ought to incorporate intuitive interfaces, obviating the need for extensive instructions. Interactive tasks with immediate hints and feedback might be particularly advantageous for students with weaker mathematical abilities. Such tasks alleviate maths anxiety by fostering mathematical thinking without resorting to mechanical problem-solving.

# 5 CONCLUSIONS

Devlin (2008) posits that the forthcoming revolution in mathematics will primarily alter the presentation of mathematical content, as opposed to the content itself. Advancements in e-assignment systems and feedback mechanisms, such as the integration of adaptive formats personalised for individual students, might fuel this progression. However, substantial doubts persist regarding the extent of the learning these systems can facilitate. We presented a classification of different types of feedback and considered the challenges and opportunities of enhancing conceptual understanding in mathematics using the open-source tools STACK and JSXGraph. The hint matrix was presented as a new way to enwiden learner-centred assessment and promote learning outcomes. There is a pressing need for additional research focused on comprehending the dynamics of interactions with online courses, especially concerning the learning outcomes they produce. The developed model provides proof of concept. Future research should provide more evidence to report the results of this approach in real scenarios with students.

# ACKNOWLEDGEMENTS

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