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FOSTERING AUTONOMY IN STEM EDUCATION – THE USE OF JUPYTER NOTEBOOKS IN HIGHER EDUCATION

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Abstract
This paper examines how higher education instructors perceive the role of Jupyter notebooks in supporting autonomy within the framework of Self-Determination Theory (SDT) in higher education in sciences. Drawing on a qualitative research design, interviews were conducted with ten higher education instructors who frequently use Jupyter notebooks in their teaching. The interview data were analysed using qualitative content analysis. The findings suggest that Jupyter notebooks, as a low-threshold and interactive instructional tool, may promote autonomy by addressing students' three basic psychological needs as defined by SDT. Interview participants also emphasised the practical relevance of the notebooks for preparing students for future professional environments. Furthermore, the results indicate a growing demand for computational competencies across disciplines, driven by evolving technological requirements. At the same time, students demonstrate varying levels of prior knowledge. In response, the implementation of innovative infrastructures, such as a centralised JupyterHub, is identified as a promising strategy for providing equitable access to digital learning tools. Finally, the study considers the emerging influence of large language models (LLMs) and outlines several potential pathways through which they may interact with the principles of SDT.

1 Introduction

Competencies in the fields of Science, Technology, Engineering, and Mathematics (STEM) have become indispensable in the digital world of the 21st century, not least for addressing technological developments (Köller et al., 2021). In light of Germany's comparatively cautious position as a technology hub, it is crucial to retain and motivate students in these fields (Wörner & Kunst, 2024). Higher education institutions are therefore advised to strengthen digital and computational competences in particular by expanding digital provision and sustainable infrastructure (Köller et al., 2021).

Jupyter notebook (JN) is a software tool that may improve education in STEM subjects (Barba et al., 2019; Granger & Perez, 2021). JNs are interactive documents that allow users to execute code, visualise results, and combine explanatory text and multimedia elements within a single, user-friendly environment (*Jupyter Documentation*, 2015). They offer potential to support flexible and active learning environments in higher education and to promote students' acquisition of

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computational competences (Amoudi & Tbaishat, 2023). Higher education instructors also report that students can experience a form of creative knowledge production through the use of JNs, which aligns with the highest levels of Bloom's taxonomy (1956) (Barba et al., 2019).

From the perspective of Self-Determination Theory (SDT), a core element of effective teaching is the fulfilment of students' three basic psychological needs: autonomy, competence, and social relatedness (Ryan & Deci, 2017). In an autonomy-supportive teaching and learning environment, instructors can specifically foster these needs, thereby strengthening students' self-determined learning motivation (Reeve & Cheon, 2021). This, in turn, may have positive effects on students' engagement, well-being, and performance (Ryan & Deci, 2020). Although SDT has been extensively studied in various educational contexts over the past two decades (Wilkesmann, 2023; Wilkesmann & Lauer, 2020), it has received limited attention to date in connection with JNs or STEM education (Stiefenhofer & Zhang, 2023).

2 Background

2.1 SDT and the basic psychological needs

As an organismic macro-theory, SDT explores the conditions that give rise to different forms of motivation. Motivation is characterised by varying degrees of autonomy, from non-self-determined to self-determined behaviour, and is categorised into amotivation, extrinsic motivation, and intrinsic motivation (Ryan & Deci, 2000, 2017) (Figure 1).

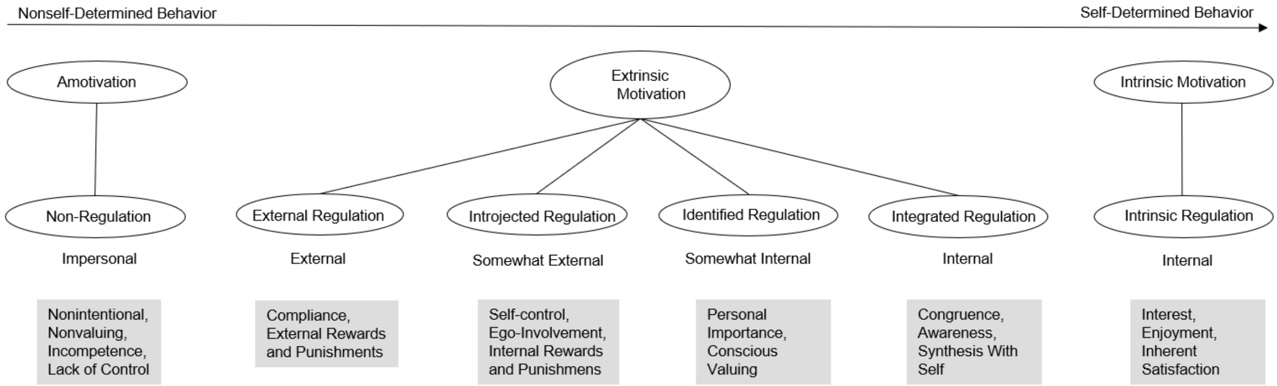

Figure 1. Self-Determination Theory (Ryan & Deci, 2000, p. 72) (own illustration)

Amotivation, the strongest form of non-self-determined behaviour, is defined as "the state of lacking the intention to act" (Ryan & Deci, 2000, p. 72), i.e. no action is taken at all or a movement sequence is imitated without any intent. In contrast, intrinsic motivation is seen as an innate tendency to engage in an activity for the enjoyment and inherent satisfaction it provides. Extrinsic motivation also involves a degree of self-determination and varies in its level of autonomy. The range includes external regulation, introjected regulation, identified regulation, and integrated regulation. Extrinsically motivated individuals aim to achieve specific outcomes, such as avoiding punishment or gaining rewards, in externally regulated forms of motivation. In the integrated form of regulation, individuals strive for congruence, which represents the stage closest to intrinsic motivation (Ryan & Deci, 2000).

Furthermore, Ryan and Deci (2009) include the terms autonomous motivation and controlled motivation within SDT. Autonomous motivation as a construct is often used in research and encompasses intrinsic, identified, and integrated forms of regulation, whereas controlled motivation encompasses external and introjected regulation (Guay, 2022; Ryan & Deci, 2009; Slemp et al., 2024) (Table 1).

Table 1. Controlled and autonomous motivation

Amotivation	*Controlled motivation*		*Autonomous motivation*		
	External	Introjected	Identified	Integrated	Intrinsic

In an educational context, students are autonomously motivated to learn when they learn out of interest and curiosity and perceive course content as meaningful (Vansteenkiste et al., 2012).

SDT also includes the continuum of internalisation within controlled and autonomous motivation. Internalisation is the process through which the underlying value of an action becomes part of an individual's value system, meaning that controlled, externally regulated behaviour is transformed into autonomously motivated behaviour (Ryan & Deci, 2002). SDT assumes that successful internalisation depends on the fulfilment of three needs – autonomy, competence, and relatedness – as described in Basic Psychological Needs Theory (BPNT), a sub-theory of SDT (Ryan & Deci, 2022). The three basic psychological needs are described as follows:

- Autonomy "refers to regulation by the self or to self-determination and authentic volition" (Legate & Ryan, 2020, p. 3), meaning that an individual's behaviour is entirely a matter of free choice (Ryan et al., 2021). Autonomy-driven actions involve taking initiative and responsibility for one's own behaviour and are supported by interest and value (Ryan & Deci, 2020). "When satisfied, students feel that they can be themselves and that they are the 'owner' of their thoughts, actions, and feelings" (Vansteenkiste et al., 2019, p. 55).
- Competence is the natural need to develop one's skills, referring to feelings of effectiveness (Ryan & Deci, 2017) and "a sense that one can succeed and grow" (Ryan & Deci, 2020, p. 1). Being recognised as competent is crucial when internalising external goals (Wilkesmann, 2023). "When satisfied, students feel confident and capable to execute a learning task and to exercise and extend their skills" (Vansteenkiste et al., 2019, p. 55).
- Relatedness is the need to belong to a social environment and to participate as a valued member in order to feel connected (Ryan & Deci, 2017). In higher education research settings, relatedness is often distinguished as relatedness to the instructor and relatedness to classmates, meaning that students have significant relationships with the instructor and with other students (Goldman et al., 2017; Loopers et al., 2024). "When satisfied, students feel strongly connected to and understood by significant others, while also displaying a reciprocal concern toward others" (Vansteenkiste et al., 2019, p. 55).

SDT posits that an autonomy-supportive environment supports autonomous motivation by initiating internalisation. Autonomy support in teaching means that instructors create opportunities for meaningful tasks and choices, allowing students to take ownership of their learning rather than creating a controlling environment that produces pressure (Ryan & Deci, 2020). According to Reeve and Cheon (2021, p. 55) "autonomy-supportive teaching emerges out of a student-focused attitude and an understanding interpersonal tone". They identify seven autonomy-supportive instructional behaviours (ASIBs), which either foster intrinsic motivation or support internalisation (Reeve, 2016; Reeve & Cheon, 2021). The foundational ASIB is adopting the students' perspective, which supports both intrinsic motivation and internalisation by demonstrating empathy and awareness of the student experience (Reeve, 2016).

Two behaviours specifically promote intrinsic motivation: inviting students to pursue their interests and presenting learning activities in need-satisfying ways. These practices encourage curiosity and provide meaningful engagement through choice (Reeve & Cheon, 2021). Four additional ASIBs aim to support internalisation. First, providing explanatory rationales clarifies the value and purpose of tasks. Second, acknowledging and accepting students' negative emotions shows sensitivity to their experiences. Third, using invitational language - avoiding controlling expressions like "must" or "should" - helps reduce pressure. Finally, displaying patience allows students to progress at their own pace and in their own way, supporting deeper engagement and self-regulation (Reeve & Cheon, 2021).

As a result, people perform better and experience increased well-being (Reeve & Cheon, 2021; Ryan & Deci, 2020). An autonomy-supportive environment in educational settings, for both instructors and students, is key to the satisfaction of basic psychological needs (Goldman et al., 2017; Loopers et al., 2024; Wilkesmann & Schmid, 2014).

2.2 The Jupyter world

Julia, Python, and R – three well-known programming languages – form the acronym Jupyter (Barba et al., 2019). The Jupyter initiative, formerly known as iPython, was launched in 2014 with the aim of developing a unified set of open-source tools for scientific research, and enabling reproducible workflows, computational narratives, and data analysis (*Jupyter Documentation*, 2015).

A key component of this initiative is the browser-based JN, which supports multiple programming languages and provides pre-configured virtual workspaces. These environments offer a collaborative and iterative setting for data exploration, visualisation, and code prototyping (Granger & Perez, 2021). Users can access JNs through various means, including local installation on personal hardware, remote access via a server, or fully managed cloud services such as Google Colab.

The Jupyter server functions as a communication hub between the browser, the notebook file, and the kernel. The kernel executes the code contained in the notebook using the selected programming language and returns the results to the user (Figure 2).

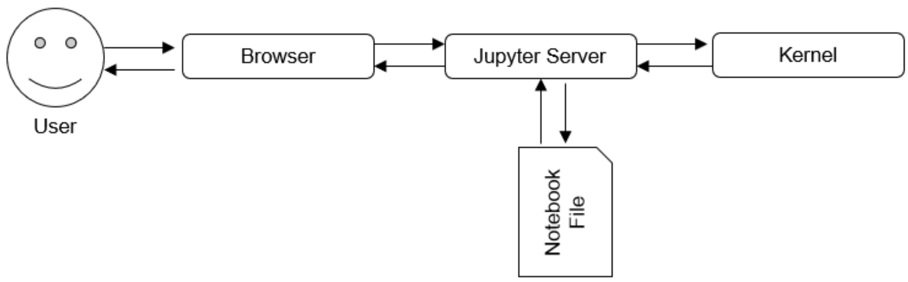

Figure 2. Jupyter notebook interface (Jupyter Documentation, 2015) (own illustration)

In educational contexts, Barba et al. (2019) reported various use cases for JNs. For example, educators highlighted the ease of switching programming languages in large courses, managing high student enrolments, and transferring course materials between instructors. Compared to traditional teaching approaches that rely on other software - or none at all - JNs reduce the administrative burden on instructors. They eliminate the need to secure sufficient university computers or allocate substantial lecture time to familiarising students with complex tools.

3 Literature review and research question

In relation to autonomy-supportive teaching practices, JNs appear promising. The active learning environment and extensive instructor-student and student-student interaction provided by JNs suggest that, when used appropriately in teaching, JNs may enable students to experience autonomy, relatedness to the instructor and other students (Amoudi & Tbaishat, 2023; Barba et al., 2019), and an increased sense of competence (Farah et al., 2020).

With regard to autonomy as a student need, the technical characteristics of JNs make self-determined learning possible because location, time, and students' hardware capabilities are not limiting factors (Granger & Perez, 2021). Students and instructors can access JNs anywhere, at any time, and on any hardware. They are not restricted to a single programming language. This personalisation allows instructors to design notebooks in such a way that multiple solutions are possible, enabling students to tailor their work to their own preferences (Barba et al., 2019).

Studies investigating the impact of JNs in teaching settings have found that they may also have the potential to develop students' essential skills, such as technical skills, problem-solving abilities, and critical thinking (Amoudi & Tbaishat, 2023; Farah et al., 2020; Johnson, 2020). Nonetheless, from an outcomes-oriented perspective, one study found that, in a computer science course for advanced programmers, students using JNs did not achieve significantly better learning outcomes than those in the control group (Al-Gahmi et al., 2022). Johnson (2020) also points out that poor coding practices could be reinforced. By contrast, studies focusing on courses that do not require programming skills found that JNs can indeed promote computational thinking (Farah et al., 2020). Moreover, Amoudi and Tbaishat (2023) have shown that students are encouraged to achieve higher-order learning objectives.

The collaborative environment provided by JNs (Amoudi & Tbaishat, 2023; Barba et al., 2019), indicates that the final construct of BPNT, relatedness, can also be supported. Collaborative learning "is a situation in which learners interact in a collaborative way" (Dillenbourg, 1999, p. 8). For instance, JNs have been shown to be effective in teaching through interactive lecture notes and the flipped classroom (Johnson, 2020). Also known as the inverted classroom, the flipped classroom concept involves collaborative group learning activities in the classroom and individual, computer-based instruction outside the classroom (Bishop & Verleger, 2013). Amoudi and Tbaishat (2023) point out that it is essential to use JNs within an experimental learning environment, such as the flipped classroom environment. As a result, students are encouraged during lectures and enjoy the sessions.

As generative artificial intelligence (AI) – particularly in the form of large language models (LLMs) – gains increasing significance and prevalence in higher education, not least due to the availability of open-source models such as OpenAI's ChatGPT (Lo, 2023), this topic is of particular relevance to this study. LLMs are powerful models for processing and generating natural language (Kelbert et al., 2023). Students are often able to solve programming tasks efficiently with the help of LLMs (Boguslawski et al., 2025; Jošt et al., 2024). Within the framework of SDT, LLMs may be conceptualised as potential mechanisms of action that influence motivational processes.

"What is clear is that no technology has an impact on learning in its own right; rather, its impact depends upon the way in which it is used" (Luckin et al., 2012, p. 9). In line with this statement, it is important to note that the use of JNs in higher education does not automatically result in an autonomy-supportive learning experience. The way in which instructors use JNs is critical to realising their full potential. It is therefore essential to investigate how instructors perceive and utilise JNs in their teaching practice.

Given the importance of autonomy support in STEM education, the limited attention to JNs in this area of research, and the disruptive influence of generative AI on how programming skills are taught and learned, addressing this research gap becomes increasingly urgent. Specifically, it is necessary to explore how JNs can be employed, through the lens of SDT, to help shape the future of STEM education. This leads to the following guiding research question:

How do higher education instructors perceive the influence of JNs on autonomy support within the framework of SDT in STEM education?

4 Methodology

4.1 Aim of the study and data collection

Since no comparative data were available, a qualitative research design was chosen to address the research question. Interviews were conducted with higher education instructors who frequently use JNs in their courses.

This was based, among other things, on the *JupyterHub.nrw* project, which provides instructors, researchers, and students in North Rhine-Westphalia with low-threshold access to JNs by embedding them into higher education institutions' infrastructure via a central JupyterHub. JupyterHub is a multi-user platform specifically designed to provide access to JNs via the web, hosted on centralised hardware; that is, a Jupyter server is launched for each user (Jupyter Documentation, 2015).

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The *JupyterHub.nrw* project aims to enhance the quality of teaching at higher education institutions by offering low-threshold access to pre-configured virtual work environments. This allows students to use data analysis tools and common scripting languages regardless of their personal technical setup. The need to install digital tools locally on one's own device – previously identified as a significant challenge by Johnson (2020) – is thereby eliminated. At the same time, instructors are relieved from the burden of maintaining their own servers or directing students to third-party cloud services, as *JupyterHub.nrw* is fully integrated into the information technology infrastructure of participating higher education institutions.

The objective was to examine the use of JNs in higher education and to determine, from the instructors' perspective, the extent to which they contribute to the promotion of learner autonomy, in order to derive implications for both practice and research in STEM education at higher education institutions.

4.2 Participants and procedure

Ten higher education instructors who actively integrate JNs into their teaching were recruited as interview participants (IP). Recruitment was conducted via the *JupyterHub.nrw* project, through which eligible instructors were contacted. Inclusion criteria required frequent and active use of JNs in teaching contexts. The guiding principle was to interview all available and willing participants. The sample included five research associates, one postdoctoral researcher, and four professors, representing nine different departments across five higher education institutions in two German federal states (Table 2).

Table 2. Interview participants

	Profession	*Affiliation*
IP1	Professor	Department of Computer Science
IP2	Research associate	Chair for High Frequency Technology
IP3	Professor	Chair of Interconnected Automation Systems
IP4	Professor	Neural Data Science
IP5	Research associate	Department of Computer Science
IP6	Professor	Inorganic Chemistry
IP7	Postdoctoral researcher	Department of Physics
IP8	Research associate	Practical Computer Science
IP9	Research associate	Institute of Transport Logistics
IP10	Research associate	Data Literacy Education

A semi-structured interview guide was used, containing primarily open-ended questions regarding the use of JNs in educational contexts. The interviews were conducted using a video-conferencing tool, recorded with participants' consent, and subsequently transcribed and anonymised.

The data were analysed according to Mayring's (1991) recommended step model, which includes paraphrasing, reduction, and coding of the interview content. Certain analytical procedures were adapted to the specific context of this study in accordance with Mayring (1991). The analysis was carried out using MAXQDA software. Following the guidelines of Kuckartz and Rädiker (2024), particular attention was paid to the development of a clearly structured category system that is closely aligned with the research question.

Accordingly, a combination of deductive and inductive category development was employed. Deductive categories were derived from established theoretical frameworks, whereas inductive categories emerged from the material (Mayring, 1991). Given the study's alignment with SDT, the deductively defined main category was *autonomy support*, which encompassed the subcategories *autonomy*, *competence*, and *relatedness*. In addition, the inductive subcategories *practical relevance* as a need and *use of AI* emerged within this head category. During the analysis, three further inductive categories were identified. Among them, the head category *perceived role and impact of JNs in teaching* was developed, comprising the subcategories *evaluation of JNs, integration into teaching,* and *instructional design*.

To approximate intercoder reliability, the procedure proposed by Kuckartz and Rädiker (2024) was applied. Two interviews were independently recoded by a second researcher using the existing category system. The aim of this process was not to generate a quantified reliability coefficient, but to ensure high coding quality by identifying and discussing the underlying causes of coding discrepancies. The resulting categorisations were subsequently compared and jointly reflected on.

5 Results

5.1 Perceived role and impact of JNs on teaching

Within the category of “evaluation of JNs”, the interviewees emphasised that the use of JNs offers a significant advantage for teaching, primarily because no local installation is required when a centralised JupyterHub is used. "Everyone has the same versions, the same conditions, and essentially a fully pre-configured tool", as IP1 described the standardised starting point. This promotes equal opportunities, as students with less powerful hardware can also actively participate in courses. Several interviewees reported that some students attend programming courses using tablets or even smartphones.

Particularly, the cell-based execution and the combination of text and code within a single notebook allow instructors to present content in an accessible and illustrative manner. As IP10 put it, this enables a form of storytelling in teaching through the immediate visualisation of results. JNs offer instructors the opportunity to design interactive teaching formats that actively engage students and encourage participation: “[…] so that students can really concentrate and don’t have to take unnecessary notes, but can actually pay attention - even open it themselves, interact with things, try things out.” (IP1)

However, some respondents pointed out that JNs may have limitations when used for more complex purposes, such as software development. For students, JNs may become a comfort zone, potentially discouraging them from learning how to install and use more suitable software tools: “At the same time, I think it’s also important to eventually move away from these notebooks. I’ve found that many – for example, students writing their master’s theses – still prefer to work with notebooks, but at some point, that just reaches its limits.” (IP7).

The interviewees gave various reasons for integrating JNs into their teaching. In some cases, courses were newly taken over and materials had to be created from scratch. In others, the courses had already developed historically in the Jupyter format, and instructors received substantial support from their department: “We were lucky to have a professor who said: this Jupyter notebook, that’s the way to go.” (IP5). The flexibility of JNs was also highlighted. Since multiple virtual environments are supported, teaching can be quickly adapted depending on current trends in practice. This also addresses the heterogeneity of students’ prior knowledge.

The *JupyterHub.nrw* project also provided a good opportunity for introducing JNs, as its infrastructure enabled use without technical hurdles. As a result, JNs replaced traditional paper-based worksheets. A presentation plug-in in the notebook also allows “an interactive script to be created, which can also serve as the slides,” (IP1), meaning animations and videos can be integrated into the script.

“So, I didn’t prepare worksheets, but used JupyterHub in class as a simple setup system, so they didn’t have to install anything, and I just did small coding exercises with them.” (IP1). In some courses, a flipped classroom approach is also used: students work through JNs independently during self-study, while in-person sessions are reserved for discussions, clarification of open questions, and deeper engagement with the content. However, this offering is often only taken up to a limited extent, as only a small number of students attend in-person sessions: “There are always only a handful of students present.” (IP4), even though this format could also enhance social connectedness.

5.2 Autonomy support

On the topic of autonomy, several interviewees differentiated between Bachelor's and Master's students, as well as between mandatory and elective courses. As IP1 noted, “there is significantly less intrinsic motivation in mandatory courses than in elective ones.” IP1 described two distinct strategies: in Master's-level elective courses, students should be encouraged to install JNs locally “simply so that they learn independently: how do I help myself.” In Bachelor's mandatory courses, the approach should be the opposite: teaching should involve low-threshold tools, for which browser-based JNs are particularly suitable. “First show the students: what cool things can I actually do with this. I would say, first tease it. Instead of going through a long-suffering process, do it the other way around: ‘here, everything is already set up, you can use it’. So low-hanging fruit as an entry point.” (IP1)

In response to the request for independent programming in JNs, the interviewees also reported that students often initially reacted with uncertainty — not due to the tool itself, but due to the demand to actively engage. The autonomy associated with this was seen by instructors as a challenge, particularly for Bachelor's students. “Natural curiosity is largely trained out of students in the school context” (IP6). “When you start with it, of course there is a lot of groaning at first. Unfortunately, what is most comfortable is not always what is best for students, and at that point, they are challenged a bit because they have to work their way into a new tool themselves.” (IP1). However, over the course of the semester, this attitude reportedly changes to one of clear appreciation for JNs: “But by the middle of the semester, the realisation occurs: ‘oh wow, I can actually do a lot with this and, wow, it really helps me’.” (IP1).

Group work is generally encouraged by the interviewees. “But in fact, we don’t force students to work alone; we explicitly encourage them to talk to their neighbours about the tasks and try to figure them out together. And that works very well. I have the impression that many students help each other and work through the tasks collaboratively.” (IP7)

Students are free to decide whether to work on JNs individually or in groups. In the context of group work, IP5 observed: “They really sit there like people used to do when playing games, in front of the same computer, and work through it together.” IP6 also observed playful interaction between students when working on JNs collaboratively: “And then you could tell that their play instinct was triggered, because then everyone started saying: ‘hey, did you see, when I do this, that happens’, and then they started talking to each other.”

The interviewees identified another relevant motivational factor: the practical relevance of the course content. The respondents agreed that “you can only motivate someone if they already bring a certain interest in the topic. And at that point, I have to pick them up.” (IP6). Some instructors refer to students’ future professional environments and enrich their teaching with real company data and tasks, or integrate discussions on current societal and technological developments to highlight broader disciplinary contexts. IP5, for instance, uses entertaining datasets to make complex concepts more tangible: “Then I always try to find data that people are interested in. For example, I found Marvel scripts with the dialogues from the movies in them. At the beginning, we look at some statistics about the books, compare them: ‘how many words are actually in there? How many of those words are repeated?’ Then we make a few plots.” (IP5)

The motivation to use JNs in teaching also stems from a desire to ensure practical relevance and offer contemporary teaching. “Why did I change it? Well, because in practice, data science is already done using these tools, and in my view, students shouldn't learn statistics like mathematicians, but rather like computer scientists or data scientists. And of course, it helps to get to know the actual toolbox used in practice, like Jupyter notebooks, and to interact with it.” (IP1). Another important aspect is the interest in promoting active student participation, in order “to motivate students to think more for themselves and to participate more actively.” (IP3).

According to the interviewees, developing programming skills is becoming increasingly challenging due to the varying levels of prior knowledge: “And I often have students from different programmes. Most come from computer science, but I also have students from communication studies or completely different backgrounds. So sometimes the prior knowledge is different, and for that reason, I take more of an interactive approach. And notebooks are usually better suited for that.” (IP4).

For most of the respondents, however, programming is not the primary learning goal but a means of achieving a broader educational objective: “In my teaching, it’s often not about teaching students programming itself, but rather about using programming concepts or languages to analyze data or generate models.” (IP4).

Several interviewees stated that students should learn programming explicitly in other courses, but they also emphasised that the notebook format is accessible even for students who have not yet gained programming experience. Some instructors rely on cross-faculty or even higher education-wide courses, as programming skills taught in computer science are also needed, for example, in mechanical engineering. The interviewees agreed that interdisciplinary skills are becoming increasingly important, especially as computer science knowledge is no longer required exclusively in data science programmes.

“And people who still think that programming is only done by computer scientists, and that chemists are in the lab mixing chemicals - that may have been the case once, but it’s not like that anymore, and it never will be again. Nobody should be under that illusion.” (IP6).

Several interviewees also observed that students are increasingly using LLMs such as ChatGPT, especially for traditional programming tasks in the JN format. This becomes apparent in exams or assignments when students use Python libraries that were not covered in the course, or when they are unable to explain their code in oral exams. Instructors noted both reflective and unreflective uses of LLMs. IP5 commented: “Weaker students tend to use it as a shortcut or brain substitute, I would say.”

The potential threat this poses to the development of computer science competence was also discussed: “You’re outsourcing the competence, or you get the feeling that you don’t need to acquire it yourself, because there’s ChatGPT that can do it for you. The problem is, that’s not true. You can only use ChatGPT if you already have a certain level of competence.” (IP6). Other interviewees, who view programming only as a means to an end for broader learning objectives, were less critical of LLM use: “The focus is not on learning to program itself, but on using it, and in that context, ChatGPT is a good tool.” (IP4)

6 Discussion

The interviews suggest that the participating instructors perceive the use of JNs as having a positive impact on support for student autonomy. This begins with the absence of installation requirements, which enables active and equitable participation, and extends to the combination of code and text cells within a notebook, which allows for more accessible explanations of content. These findings align with results already reported in the literature, particularly due to the interactive nature of JNs (Amoudi & Tbaishat, 2023; Granger & Perez, 2021; Johnson, 2020). Given their diverse applications, Granger and Perez (2021, p. 6) argue that "Jupyter helps humans to think" by facilitating analysis, decision-making, creation, evaluation, and more.

The results also indicate that the autonomy-supportive nature of JNs, by enabling self-directed participation, may initially lead students to feel overwhelmed, especially in large, mandatory courses. However, the underlying causes of such reactions remain unclear. As this study does not include students’ perspectives, it cannot determine whether these responses are a direct result of autonomy-supportive tasks or potentially due to other factors. Given the limited research on this topic, no definitive conclusions can be drawn. In addition, focusing exclusively on autonomy support may not be sufficient to ensure comprehensive need satisfaction and successful internalisation. Recent findings by Eichhorn and Mergner (2025) also emphasise the importance of addressing students’ experiences of competence and social relatedness in teaching settings.

Nevertheless, participation remains accessible, as students can use JNs independently of time, location, or hardware. Stiefenhofer and Zhang (2023) also found that JN-based teaching enhances students’ autonomy in the learning process, as it supports individual learning paces and preferences. In this way, the challenges posed by heterogeneous prior knowledge and experience in digital tools and programming, especially in interdisciplinary contexts, as identified in this study, can be addressed. Similarly, a study by Al-Gahmi et al. (2022) reported that students in JN-based programming courses tended to achieve better performance outcomes. This finding suggests that

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JNs may support autonomy, as improved performance is associated with the satisfaction of basic psychological needs (Ryan & Deci, 2020). However, it should be noted that these findings were not statistically significant due to the small sample size (Al-Gahmi et al., 2022). Despite this, the present study supports the findings of Stiefenhofer und Zhang (2023) and Al-Gahmi et al. (2022), indicating that, from the instructors' perspective, JNs provide favourable conditions for supporting student autonomy.

This study also highlights that voluntary group work can help students engage with content in a self-directed and playful manner. The immediate feedback provided by JNs on student input fosters joyful peer-to-peer interaction. Another approach to fostering social relatedness is collaborative problem-solving: confronting students with real-world challenges that they must address in group settings. According to Xu et al. (2023), this approach enhances critical thinking and learning progress, particularly in mathematics education, and represents an effective way to combine practical relevance and social embeddedness.

The practical relevance of course content can be interpreted as a need for meaning or perceived significance, which – like autonomy, competence, and relatedness – may contribute to the internalisation of learning goals. The findings indicate that respondents placed significant importance on this construct. This may apply both to preparing students more effectively for the demands of the professional world and to enhancing instructors' own teaching experience, given that instruction is perceived as more rewarding when students are engaged and actively participate. An experimental study by Johansen et al. (2023), which integrated this dimension into the framework of SDT, examined a group of STEM students who were given tasks considered relevant, while a control group received traditional assignments. The results showed that students in the experimental group reported significantly higher levels of autonomous motivation compared to the control group.

On the basis of the findings of this study, the development of programming-related competences may be either supported or hindered by the use of LLMs, depending on students' proficiency levels and the course learning objectives. Where programming is not the primary learning goal, LLMs can support autonomy by allowing students to reach results more quickly and avoid getting stuck on syntactic details (e.g., placement of parentheses in code). A recent study found that negative emotions that undermine perceived competence can be reduced through LLM use, as students are more willing to ask questions without hesitation (Boguslawski et al., 2025). However, when programming itself is the primary learning objective, LLMs are seen by respondents as a potential risk to the development of core competencies, depending on students' performance levels. A study by Jošt et al. (2024) showed that greater reliance on LLMs during programming tasks correlated with lower final grades.

Previous research has shown that instructors who work in autonomy-supportive environments are more likely to create autonomy-supportive learning conditions for their students (Wilkesmann, 2013; Wilkesmann & Schmid, 2014). The present study supports this relationship: instructors recognise that certain design features in teaching can influence student motivation and express interest in implementing them, as they themselves are autonomously motivated to teach. From their perspective, the use of JNs facilitates consideration of students' basic psychological needs in STEM education. Thus, a positive association between the use of JNs and autonomy support may be assumed from the instructors' perspective.

7 Conclusions, limitations, and future research

The study indicates that JNs offer favourable conditions for supporting autonomy in STEM education. Their structure and interactivity appear to facilitate the implementation of autonomy-supportive instructional practices by educators. In line with the research question, the findings indicate that higher education instructors report positive experiences with JNs, particularly when provided through an organisation-managed JupyterHub infrastructure. Access to such up-to-date technological tools is perceived as a catalyst for effective didactic implementation in STEM fields.

Projects such as *JupyterHub.nrw* may have resource-enhancing effects on higher education institutions and may therefore indirectly contribute to improved student learning outcomes. To support this assumption, further empirical research is required. The aim of future studies should be to quantitatively assess the impact of teaching innovations such as JNs and to highlight their implications for higher education.

Practice-oriented study programmes may ease the transition into the labour market, resulting in macroeconomic efficiency gains. However, a key prerequisite for this is strong institutional support for teaching innovations on the part of academic departments, which is essential for their long-term integration into curricula (Wilkesmann & Lauer, 2020). In this context, it should also be systematically examined to what extent computer science-related competencies have gained significance across disciplines in the labour market – including also outside of the STEM fields – in order to provide well-founded recommendations for the implementation of accessible digital tools in higher education.

However, the interviews also reveal ambivalent perceptions regarding the use of LLMs. The limited literature available on this topic also points to mixed findings (Boguslawski et al., 2025; Jošt et al., 2024). Based on this interview study, it can be assumed that reflective use of AI may act as a moderating variable that strengthens the relationship between autonomy support and students' perceived autonomy as well as competence. Future research should aim to investigate these hypotheses using quantitative methods. It would also be valuable to explore whether this effect varies depending on students' performance levels. Furthermore, a fundamental question arises as to what extent programming competencies are still considered necessary in the era of increasingly powerful LLMs, particularly given that instructors in this study largely viewed programming as a means to an end.

Despite the broad range of expertise and disciplinary backgrounds of the interviewed higher education instructors, the generalisability of the findings is limited by the small sample size. It is also plausible that the study primarily attracted instructors who are already autonomously motivated, which further limits the generalisability of the findings. This is particularly relevant, as the integration of teaching innovations is considerably easier within an autonomy-supportive environment (Vansteenkiste et al., 2012; Wilkesmann & Schmid, 2014). Since this study captured only instructors' perspectives, future research should include students' views to gain a more comprehensive understanding of the mechanisms through which teaching innovations unfold their effects.

In conclusion, for higher education institutions, the integration of a JupyterHub infrastructure offers a scalable and inclusive approach to support autonomy, especially in STEM education, by reducing technical barriers and fostering flexible, student-centred learning. Instructors are encouraged to leverage JNs not only for their interactive features, but also as tools to promote autonomy-supportive teaching practices aligned with SDT. For students, JNs provide opportunities for self-paced, meaningful engagement and collaborative learning, which can enhance motivation and skill development. Ultimately, the study underscores the importance of aligning digital tools with pedagogical strategies that address the basic psychological needs to support internalisation.

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